RADIOCOMMS
Designer's guide to selcall

ANALOGUE
Synchronous alternative to PLLs?

APPLICATIONS
Picking up on wireless LANs

DIGITAL
Using $I^2C$ beyond the board

PC ENGINEERING
Motherboards through the ages

COMPONENTS
Digital signal processor for FM demodulation

MAINTAIN CONTROL WITH RS232
The PC82 Universal Programmer and Tester is a PC-based development tool designed to program and test more than 1500 ICs. The latest version of the PC82 is based on the experience gained after a 7 year production run of over 100,000 units.

The PC82 is the US version of the Sunshine Expro 60, and therefore can be offered at a very competitive price for a product of such high quality. The PC82 has undergone extensive testing and inspection by various major IC manufacturers and has won their professional approval and support. Many do in fact use the PC82 for their own use!

The PC82 can program E/EPROM, Serial PROM, BPROM, MPU, DSP, PLD, EPLD, PEEL, GAL, FPL, MACH, MAX, and many more. It comes with a 40 pin DIP socket capable of programming devices with 8 to 40 pins. Adding special adaptors, the PC82 can program devices up to 84 pins in DIP, PLCC, LCC, QFP, SOP and PGA packages.

The unit can also test digital ICs such as the TTL 74/54 series, CMOS 40/45 series, DRAM (even SIMM/SIP modules) and SRAM. The PC82 can even check and identify unmarked devices. Customers can write their own test vectors to program non standard devices. Furthermore it can perform functional vector testing of PLDs using the JEDEC standard test vectors created by PLD compilers such as PALASM, OPALjr, ABLE, CUPL etc. or by the user.

The PC82’s hardware circuits are composed of 40 set pin-driver circuits each with TTL I/O control, D/A voltage output control, ground control, noise filter circuit control, and OSC crystal frequency control. The PC82 shares all the PC’s resources such as CPU, memory, I/O hard disk, keyboard, display and power supply.

A dedicated plug in card with rugged connecting cable ensures fast transfer of data to the programmer without tying up a standard parallel or serial port. Will work in all PC compatibles from PC XT to 486.

The pull-down menus of the software makes the PC82 one of the easiest and most user-friendly programmers available. A full library of file conversion utilities is supplied as standard. The frequent software updates provided by Sunshine enables the customer to immediately program newly released ICs. It even supports EPROMs to 16Mbit.

Over 20 engineers are employed by Sunshine to develop new software and hardware for the PC82. Not many competitors can boast of similar support!

Citadel, a 32 year old company are the UK agents and service centre for the Sunshine range of programmers, testers and in circuit emulators and have a team of engineers trained to give local support in Europe.
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In conjunctions with Allegro distributor Ambar Cascom, we present a technology primer and a free samples service for the first 500 readers replying with the special card bound into the journal. Discover the benefits of the latest magnetic transducer technology.

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Right to communicate

One cannot always say that advances in electronics bring universal benefits but one development here in the UK looks more promising than most.

Last month saw the launch of a new mobile telephone service, Orange, run by the Hong Kong operator, Hutchison Telecom. This brings the number of mobile phone systems operators in the UK to four.

The new service is causing some consternation among telecoms industry pundits who would claim that four separate systems is at least one too many... They fear that competition will jeopardise payback on the investment required to set these services up. The old but profitable analogue mobile phone networks represent well over £1 billion each. We don't know yet how much the operators will eventually have to spend on the newer networks for acceptably complete coverage but it will be a lot more than this.

The existing analogue services can provide between the two of them room for 6.5 million users. The digital GSM services – One-2-One and Orange – will have a capacity three or four times that in subscriber numbers. This expansion represents a wireless network capacity which begins to rival the standard public service wired network. Phones and phone calls where you want and when you want, but not yet at a price which matches the public telephone system call charges.

This strikes me as odd. Buried wires are as expensive to maintain as they are inflexible to use. How much investment does the existing wired network represent? One can only guess, £50 billion does not seem like an unreasonable estimate with a maintenance cost to match. Yet land line call and rental charges are cheap in comparison to the mobile subscriber charges. Could not the mobile operators begin to compete with mass market tariffs?

Network installation is more or less a fixed charge such that increased traffic volumes do not significantly increase system operating costs. Yet the social and commercial benefits of wider mobile phone ownership are not often mentioned: more efficient manpower usage in business, easier communications for vulnerable sectors of the population, greater public involvement in the prevention of crime.

It all comes down to the fact that accessible communications makes for a better society. And there is nothing more accessible than a mobile phone.

One might argue that the Government has done enough by allowing free market competition to throw up competing telecomms operators with their own marketing agendas. But it could be equally argued that a tilt towards a mass subscriber market would not have been out of place in the licensing arrangements. After all, the Government is happy to do this when it comes to broadcasting which is why it empowers bodies such as the ITC.

Electronics has given us at little cost one-way communication to wherever we happen to be in the form of radio and tv. It seems logical that it should do the same in enabling us to talk to each other.

Frank Ogden
**Licensing shakeup heralds spectrum sell-off**

The British government is rethinking its policy on licensing radio spectrum. In the future it will be easier to get licences to use radio technology, but they will cost more, especially if the technology does not make efficient use of the spectrum. The licences will probably be auctioned to the highest bidder. By the DTI's own estimate, electronics will be the world's largest industrial sector in the year 2000. Much of the new technology will rely on radio links instead of wires. The DTI says it wants to stimulate innovation with the increased use of radio technology. But although the outbreak of peace has encouraged the military to relinquish some of the radio frequencies it was holding on a just-in-case basis, demand will always far exceed supply.

"There can never be any completely new spectrum" says Jim Norton, Chief Executive of the DTI's Radiocommunications Agency, which currently allocates frequencies. "But new technology can make more efficient use of what there is. We have to encourage people to use that technology".

The RA has now published a consultative document, *Future Management of the Radio Spectrum*, and is inviting comments.

When licensing frequencies the RA currently charges enough to cover its administration costs. There is thus no incentive for licence-holders to use their spectrum efficiently. The RA wants more flexibility when charging so that those who waste spectrum by using old-fashioned radio systems will have to pay more than those who use new technology which wastes less spectrum. The transition from analogue to digital technology, says the RA, would have a "profound effect" on spectrum efficiency.

The RA would like Britain to follow Australia and New Zealand, and auction frequencies to the highest bidders. Successful bidders could then sell or subcontract the frequencies. Radio allocations cannot currently be transferred in the UK.

The RA also wants to subcontract the job of allocating some frequency blocks to independent spectrum management organisations. The RA would then act as a wholesaler. The aim is to make it easier for people to get licences.

The status of licence-exempt services which pay no licence fee would also have to be resolved. These services rely on equipment which the public can buy and use without needing any licence. They already include cordless phones, remote controls, security devices, and burglar alarms which people can fit without needed to lay wires.

The consultative document is available free from the Radiocommunications Library, Waterloo Bridge House, Waterloo Road, London SE1 8UA. Comments should be sent to Laurence Green, PO Box 3989, London SE1 8YD. Cut-off date is 22 July.

**Camera chip for less than $10**

Edinburgh-based camera-on-a-chip designer VLSI Vision (VVL) has introduced its first high volume standard product - a single chip camera which costs less than $10. VVL already has customers lined up for the device which integrates a 160 x 160 pixel array with the A/D converters necessary to produce a digitised image. One application is expected to be in the emerging video communications market.

The device, called the WL1070, includes all the control circuits required for an autoexposing camera and its 30mA current consumption will allow it to be used in hand-held cameras. The device has a single element plastic lens.

VVL has been integrating image sensing arrays with A/D conversion and digital signal processing functions for the last three years.

---

**Poor reception for new satellite**

Three million homes in the UK, and 12 million more round Europe will find that their dish systems will need modification or replacement to receive signals from the new satellite which Astra plans to launch this autumn.

Luxembourg company Societe Europeenne des Satellites, launched its first satellite five years ago, and now has three, known as Astra 1A, 1B and 1C, at the same point in space, at 19° East. Each broadcasts 16 tv channels in the frequency range 10.95-11.7GHz. Thus one dish aerial and one receiver can receive a total of 48 channels.

SES will launch a fourth satellite, 1D, this autumn. Although 1D was planned as a backup, to take over transmission duties if there is any technical failure on 1A, 1B or 1C, broadcasters want more channels for new programmes. So Astra has said it will let them use 1D to provide 16 new channels.

The 1D satellite will have to broadcast the new channels between 10.7 and 10.95GHz. Astra's estimate is that 90% of existing dish systems will not work properly in this band.

SES says it started warning receiver-makers about the need for wider frequency design in early 1992, and published a technical specification in December 1992. But manufacturers are only now starting to sell wideband receivers, labelled "1D compatible". SES fears that some firms will now try and sell old stock, which cannot receive from 1D, before the public understands the problem.

British companies Pace and NTL (formerly the research laboratories of the disbanded Independent Broadcasting Authority) have joined forces to make digital receivers for home use. Nokia of Finland has teamed up with US company TV-Com to make rival models. All will use MPEG-2 digital compression. Pictures compressed to a rate of 2MBit/s give quality similar to VHS tape, and let each satellite channel carry up to 16 programmes. At rates of 4 or 8 Mbit/s, picture quality is perfect, but each satellite channel can carry only four or eight programmes.

European satellite operator Eutelsat has demonstrated the technical viability of a novel twist to the idea. Its transmitters have a frequency range of 36MHz. Eutelsat will use 27MHz to broadcast a programme in conventional analogue form, and the other 9MHz to deliver an 8MBit/s data stream, which carries 1.2 or 4 digital tv programmes.

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B.F.
Microsoft in space

Nothing grabs the headlines like big numbers, especially when they come from Bill Gates, the multi-billionaire founder of Microsoft. But even the most imaginative aerospace engineers caught their breath last month when Gates revealed a plan to build a $9bn global computer network using no fewer than 840 low Earth orbit (LEO) satellites.

The scale of what Gates and his partner mobile phone entrepreneur Craig McCaw are proposing is so much larger than any satellite project past, present or planned that it is all too easy to either dismiss it out of hand or marvel at the audacity.

But Gates and McCaw, with the help of NASA space scientists, are only part of the latest drive, which includes many of the world's largest telecommunications operators, to build mobile communications networks using extraterrestrial infrastructure.

This is virgin territory and opinion is divided on the most feasible technology. But engineers with years of experience of building and launching satellite systems have expressed doubts over the feasibility of using a network of over 800 satellites.

Teledesic, the company Gates and McCaw have set up to develop their global LAN, is proposing to create an orbiting packet-switched data network of 840 LEOs, 40 satellites in each of 21 polar orbits some 700km above the earth. Computers and hand held terminals will be connected around the world using 30GHz uplinks and signals will be routed in space around the network of satellites.

The question is, even if it were feasible to launch and maintain that many satellites, would they be able to offer an acceptable service which is proposed to include carrying and switching not only 16kb/s data links, but also broadband video transmissions up to 2Gb/s?

International satellite operator Inmarsat has already rejected the use of LEOs for its satellite-based mobile phone system, while Motorola's Iridium satellite phone project has already revised the number of LEOs it will use from 77 to 66.

Inmarsat decided there were too many uncertainties in launching and maintaining a network of 54 LEOs. But an important factor was system complexity with most calls needing to be switched between LEO satellites.

There is no technical precedent for the proposal. A single network of 50 LEOs - let alone 840 LEOs - has yet to be created. The nearest equivalent is the US and Russian global positioning systems. The GPS satellite system created by the US defence department uses a network of 24 LEOs. "But that took 15 years to create and many satellites were lost along the way," said a spokesman for Inmarsat. However, that may not be a fair comparison, as the US defence department had no obligation and little motivation to rapidly roll out all the satellites needed for a commercial GPS service. The proposed mobile communications services will have every commercial incentive to overcome the technical and regulatory hurdles and launch satellites quickly, Chris Elliott, a satellite specialist at Smith System Engineering, believes the only questions facing Teledesic and Iridium are financial and regulatory rather than technical: "Least of the worries is the technology, you can buy your way out of most problems," said Elliott.

But it costs money to launch and maintain a network of LEOs, which may each cost as little as $2m. The Russian Glonast satellite positioning system has had more problems. Its LEOs have failed after as few as 18 months' operation. The scale of the Teledesic plan magnifies the difficulties associated with launching LEOs. Even a 10% failure rate could be cost crippling to the dreams of Bill Gates. Even if the launches were successful, there are still uncertainties over the feasibility of constructing a digital communications network with the latest asynchronous transfer mode (ATM) switches in space. Satellite links at 30GHz are certainly not trivial, said Elliott. Another option is to route signals back down to earth stations where they could be switched using terrestrial networks. The speech delays due to the multiple hop satellite links could be anything up to a second.

Teledesic's plan relies on being able to switch traffic in space at up to 2Gb/s. That is state-of-the-art digital switching technology in land-based systems. It is far from certain how they can be built into a satellite payload which requires the use of specialised radiation-hardened semiconductors to withstand the space environment.

Teledesic's plans are being taken seriously by other operators including Inmarsat. The use of the 30GHz band, if Teledesic is allowed to use it worldwide, will mean the system will not be bandwidth limited as may be the case with Iridium, according to Elliott.

Secondly, the large number of satellites will ensure areas of high population will have more than one LEO overhead at any time. This improves coverage in built-up areas and it also makes in-building access a possibility, said Elliott.

Perhaps the most important factor is that Teledesic has two of the most successful IT pioneers behind it.

Microsoft founder Bill Gates plans to build a $9bn global network relying on 840 satellites.

Powered up PowerPC

PowerPC partners IBM and Motorola are to produce a faster version of the PowerPC microprocessor as the race to push ahead of Intel Pentium performance continues.

The new PowerPC 604 will run at 100MHz with a SPEC integer rating of around 140. It will be used in new computers from IBM and Apple to be launched mid-November at the Comdex/Fall trade show. Samples of the 100MHz chip are expected ready by the middle of 1995 or earlier.

IBM and Motorola are expected to have completed the port of Microsoft Windows NT operating system to the PowerPC by the middle of this year which will open up a large part of the market that was formerly stuck with Intel architecture systems.
**Auto radar avoids collisions**

Imagine you are driving along and the car in front stops abruptly and, before you know it, your car also starts to brake thus avoiding a costly shunt.

The system which allows a constant time interval between the vehicle in front and your vehicle is called Autonomous Intelligent Cruise Control (AICC) developed by the Philips Research Centre. Jaguar Cars, British Aerospace and Rover are also a part of this project which resulted in a prototype radar which in its trials has proved a cheap safety aid to drivers.

The AICC needs a sensor to determine the distance to the car in front at all times. A strong candidate for the task is millimetre-wave radar.

Front-end hardware comprises antenna, microwave head and associated control circuitry and a signal and data processor sub-system where the sensor date is processed.

The user interface is connected to the vehicle controller via a bi-directional link.

The controller’s decisions are based on information gathered from the radar and the driver and then passed onto the brake and throttle actuators. The driver can override the system’s actions at any stage.

According to Dr Andrew Stove, the project leader who has worked on car radars since the late ‘80s, the most novel part of the whole concept is the antenna designed by the Philips Research Centre.

The basic principle of a frequency scanned antenna is not new,” said Stove. “But we’ve developed a 94GHz and 77GHz antenna that can be injection moulded, meaning low cost.”

The antenna, 160mm in length, is an array of 28 smaller phase-array antennas as radiation elements which are based on Frequency Modulated Continuous Wave (FMCW).

FMCW works on the principle of mixing the transmitted and received frequencies in the GHz range to generate a beat frequency in the KHz range making it easy to process. By measuring the beat frequency, the range to the target can be calculated following a simple formula involving the beat frequency and the velocity of the signal propagation.

Using FMCW modulation according to Dr Stove proves a good choice for an automotive radar. Because its transmission is continuous, the radar can use a transmitter with a much lower peak output power (approx. 10mW) and allows a simple Gunn-effect device to be used for the transmitter and the receiver oscillators, making the overall transmitter design simple and cheap.

The electronically scanned antenna scans the beam to map out the area ahead of the car. Previously, for automotive applications mechanically scanned antennas were used, but they proved expensive and somewhat unreliable.

As there is usually more than one target present in the scanned scene, the spectrum of the IF signal is analysed, to find the position of possible targets, by a 56001 DSP chip which performs a FFT (Fast Fourier Transform) of 256 to 1024 points, depending on the system used. The prototype system operates at a typical range of 150m.

The project is part of Prometheus and started two years ago under the ARIADNE (Application of a Realtime Intelligent Aid for Driving and Navigation Enhancement) part of the DRIVE 2 initiative. The system was developed a year ago and tested on a Rover, and more recently on a Jaguar Sovereign. It is expected to go into upper range model cars with a volume price of around £10.

**Channel 21/2**

Channel 5 Broadcasting Ltd, the consortium of MAI, Pearson and Time Warner that wants to launch a fifth terrestrial tv channel in Britain, has come up with a new answer for critics who argue that its plans to start another old-fashioned analogue service will block the UK’s future plans for a completely new digital service.

Believing that the government is on the point of making a final decision, the consortium says it will use only one of the two frequencies earmarked by the government for Channel 5 (UHF tv channel 37), leave the other (35) free for digital use and make up the difference by using completely different frequencies which it claims are available.

This, argues the consortium, will also have the happy effect of “significantly reducing” the interference which a fifth channel will cause to many millions of existing VCRs, satellite tuners and video games. The consortium estimates that returning inputs due to the new service will be £20 million.

The new plan halves the capacity of any future digital service, from 8 new programmes to 4, or 4 to 2, depending on which of the consortium’s figures you pick. Viewers will be less likely to buy a digital decoder if there is little extra choice.

**TV decoder in double standards**

General Instruments has demonstrated a dual-mode set top video decoder which is compatible with both MPEG-2 and its own DigiCipher digital TV compression algorithms.

Products based on the new DigiCipher II technology were demonstrated at the recent Cable and Satellite exhibition in London.

US MPEG-2 chip maker C-Cube Microsystems and Motorola have agreed with GI to licence the DigiCipher II technology. DigiCipher II is a follow-on from GI’s DigiCipher technology and gives the option of two compression modes (DigiCipher and MPEG-2), which ultimately allows interoperability between the two.

DigiCipher provides high quality video transmission with fast channel acquisition (300ms) and low system end-to-end delay. It is significantly cheaper to implement than MPEG-2 as it has eliminated the use of B-frames (bi-directional frames).

Although DigiCipher provides desirable features for consumer television, interactive video and video-on-demand, it has retained its open architecture so it can provide future services such as computer generated images and still images sent down low bit rate communication channels.

DigiCipher was introduced in the US last year and is already used by US broadcast operators such as Primestar, a digital service is capable of delivering 77 channels.
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PHONE ORDERS WELCOME
Unwanted signals that sap op-amp performance

Ever-growing concern about electromagnetic compatibility has led to numerous studies of the effects of rf signals on the performance of most common electronic components. Bipolar transistors, fets and common op-amps have been extensively investigated. Most investigations have looked into the tendency of such components to rectify amplitude-modulated rf signals and turn them into unwanted radio programmes or requests for taxis.

But A. S. Poulton (Electronics Letters, Vol 30, No 4) has taken things a stage further by examining the dc performance of various common op-amps with out-of-band-interference present at the input terminals. Poulton says that while some forms of induced noise may be acceptable when integrated over a long period, electromagnetic interference can have more subtle nuisance effects that do not cancel out, particularly a change in the dc offset voltage.

Poulton’s experimental set-up simulates the sort of situation that might occur in mixed analogue and digital circuitry, where high frequency square waves are loosely coupled to the op-amp’s input. The 10MHz frequency chosen is well outside the op-amp’s normal pass band and is coupled via 10pF capacitors from a balanced signal generator. The third piece of experimental kit is a dc millivoltmeter connected to the op-amp’s output to monitor the effects of the simulated interference. All three are independently powered to avoid ground or supply line loops.

The standard test circuit employs the inverting amplifier arrangement shown in the figure, although Poulton also tests a non-inverting buffer circuit which produces broadly similar results.

Balanced square waves at 10MHz, varying from IV to 10V pk-pk, were fed to the various op-amps — including 741, TL074, TL084, TLC271, LT1077 and LMC6062. In each case, with the exception of the 741, the output voltage increased sharply and in a positive direction, with increasing rf input signal.

Poulton concludes that all op-amps appear to rectify rf to some extent, though jfet and cmos types appear to be less susceptible that those with bipolar input circuitry.

A variety of other factors, including bias levels, interference pulse length and parasitic capacitances also play a part. Poulton observes that feedback capacitance does very little to reduce susceptibility, probably because open-loop ac gain is already low at the frequencies in question.

The measured changes in dc performance noted may not be huge, but Poulton says that they can be enough to compromise the low offset that is normally taken for granted in these devices. An effective cure in many cases, is to fit a capacitor between the input pins. It must be of a sufficiently high value to bypass the rf, but still be small at frequencies...

NRPB picks up amateur gauntlet

Amateur astronomer Anthony Hopwood’s observations on the power line/leukaemia link (Natural radiation focused by power lines: new evidence, EW + WW, November, pp.912-915) have prompted the professionals at the National Radiological Protection Board to test his hypothesis — with a negative result.

At first sight this may appear a triumph of the professional scientist over the amateur. In reality, Hopwood has made a worthwhile contribution and prompted the professionals into carrying out the detailed measurements for which they alone are equipped.

In purely scientific terms, the debate still lacks some plausible theory to underpin the present rather weak epidemiological evidence. Research is progressing on two basic fronts: improvement of statistical data from population studies, and exploration of possible mechanisms that might link power cables with biological changes that would lead to cancer.

Based on measurements made with a simple Geiger-Muller instrument, Hopwood theorised that power lines might somehow focus cosmic rays, concentrating them in two parallel strips, either side of the line. Since cosmic rays are high energy particles that can — like x-rays — cause ionisation in biological material, here was what appeared to be a very plausible hypothesis. But one of many theoretical difficulties is the fact that 11kV overhead lines — the type under which Mr Hopwood made his measurements — radiate only a fraction of the energy necessary to detect a cosmic ray.

The National Radiological Protection Board (NRPB) was one of the agencies stimulated by Hopwood’s work. After an initial negative result — using professional instruments but under the medium voltage lines where Hopwood made his first measurements — the NRPB team sought the cooperation of National Grid Company to repeat the experiment under a major 440kV transmission power line at Walland Marsh.

The geology was uniform and the experimenters had access to records of the actual power flowing in the cable. In the end, the NRPB scientists still found no significant variation in cosmic ray count at any position under the power lines. The NRPB concludes, with minor reservations, that there is no way in which a focusing process could account for any suggested elevation in the risk of cancer under power lines.

Replying, Hopwood says that the failure of the professional scientists (and himself) to find any focusing of cosmic rays in recent experiments could be due to the decline in solar activity since the last solar maximum. Undoubtedly, even within the world of professional science, there are many research roads that lead nowhere... or can occasionally produce unexpected and spectacular results.

But we should never underestimate the creativity of the amateur scientist. Long live kitchen table experimenters!
Could safety net make air travel safer?

Neural networks being developed at the Georgia Institute of Technology in Atlanta could help make the world a little safer – particularly for airline passengers. Georgia networks are currently being used to help identify the risk factors that lead to a fire when an aircraft crashes.

The study, led by Dr James Mahaffey, began with a commission to help make the transport of weapons less dangerous. But in principle the technique could be used to predict the outcome of hazardous waste spills, disease epidemics or indeed any situation in which there are a large number of complex inter-relating factors.

A problem is that when risk factors are as complex and numerous as they are in aircraft operations, traditional probabilistic risk assessments are limited in what they can tell you. Mahaffey explains that you start multiplying rare probability by rare probability and end up with very small numbers that can be meaningless.

Neural networks, on the other hand, can spot weak correlations between thousands of different types of data – compared with the dozen or so that even the best human mind can visualise.

To learn enough about what happens in an aircraft crash, Mahaffey’s neural network, running on a Microway computer, had to be fed with a vast amount of data. Records of 17,000 crashes, covering different aircraft types, weather conditions, pilot experience and thousands of other likely factors proved barely adequate to train the network properly.

Nevertheless, when put through its paces using data from 2000 real-life crashes, the system correctly predicted the extent of fire in around 70% of cases. This compares with a figure of around 10% using standard probabilistic techniques.

Mahaffey’s neural network shows, perhaps surprisingly, that almost every measurable factor is correlated to some extent with whether or not an aircraft will burn when it crashes. Obviously, some factors are more closely and more strongly associated than others.

What the neural network doesn’t seem to have learned yet are the sheer practicalities of air transport. When asked to predict the safest type of aircraft with which to transport weapons it came up with two rather intriguing suggestions: a glider and a helium balloon. Next on the list of fireproof possibilities was any aircraft flying over water with empty fuel tanks.

As Mahaffey readily admits, the last example might not burn, but it would certainly crash.

Fire could be less of a risk in aircraft crashes following the work of James Mahaffey at Georgia Institute of Technology.

Supercomputer previews Jupiter blockbuster

The impact of Shoemaker-Levy 9 on Jupiter is expected to be one of the most spectacular celestial events in the Solar System. There’s only one snag as far as we on Earth are concerned; the collision will take place on the side of Jupiter facing away from us. But scientists at Sandia National Laboratories are hoping that by riding on the back of the fastest supercomputer in the world, they could, in effect, be transported into the heart of the action.

As the impact will happen on Jupiter’s dark side, no-one will see the collision directly and its evidence will reach us second-hand, either from reflections off Jupiter’s moons or else by surveying the damage to the planet’s surface as the impact site rotates to face us.

So researchers at Sandia are using their 1840-CPU Intel Paragon to improve their predictions of what is going to happen. The team, from the Computational Sciences and Mathematics Center have been concerned mainly with the processes that are expected to occur as the cometary fragments hit Jupiter’s atmosphere and disintegrate explosively. The latest update, presented at a Lunar and Planetary Science Conference at the Johnson Space Center, suggests that as the cometary fragments break up in the hydrogen/helium atmosphere they will deposit their energy in a column of hot gas at high pressure. The column will then expand explosively into the surrounding atmosphere, creating a fireball that grows upwards supersonically, at speeds...
approaching that of the incoming comet, only in the opposite direction.

The researchers are also seeking the answer everyone wants to know: what, if anything, will be visible from the Earth?

Earlier estimates have suggested that astronomers would have to rely on reflections or observations from spacecraft.

Updated orbits calculated from new images taken from the recently repaired Hubble Space Telescope now put the impacts tantalisingly close to the limb of Jupiter, the edge of the planet as seen from Earth. In fact, according to the new calculations, some of the cometary fragments will not disappear behind the planet until they have already entered the thin atmosphere 400km above the denser clouds. Less than a minute later, the hot fireball is expected to rise back into view.

Whether it is bright enough to be visible from Earth is still an open question, though it is expected to emit detectable radiation at other wavelengths - enough to validate the latest calculations.

Mains hum – or ear drum

Hum, such as that generated by the mains, can be a nuisance. But for some, it could be much more of a headache than they realise.

There can be few engineers brought up before the days of monolithic stabiliser chips who are not conversant with hum. Even in professional recording or broadcasting studios, the usual way of telling whether the equipment was switched on was to put an ear to the speaker and listen for the ever-present 50 or 100Hz. But though mains hum is now a rarity in good audio equipment, it has not disappeared from our lives entirely.

An editorial in the British Medical Journal (Vol. 308, No 6925) by professor C G Rice of the Institute of Sound and Vibration Research at Southampton University says that hum – from whatever source – still causes much annoyance and ill-health. Moreover, many reported cases of low frequency hum remain unresolved, even after extensive investigation.

Rice points out that mysterious hum have been the subject of scientific investigation for more than 20 years, in everything from universities to research establishments, companies and charities.

The BMJ editorial says that some 90% of all reported cases of noises or vibrations in the 1-150Hz region can be identified and dealt with by acoustic consultants or environmental health officers. Causes include supply utilities, industrial plant, electromagnetic radiation equipment and furnaces. But there remains a mysterious 10% of reported cases of hum where no external source can be found.

Once the obvious environmental causes have been eliminated, says Rice, an investigator should take a look at the compliant. Some variants of tinnitus, he says, can manifest themselves as a continuous or throbbing low frequency hum.

But if the victim resorts to extreme measures – such as moving house – to escape the noise, then a brain tumour is a very likely cause.

A less dramatic possibility is that some people may have increased hearing sensitivity at certain specific low frequencies, though laboratory studies have so far failed to demonstrate this unequivocally. For such people a hum which is tolerable or even unnoticed by normal people may well cause annoyance.

More research into hum is clearly needed, though as professor Rice points out, one almost insuperable difficulty is the highly individual nature of each and every case.

Mystery hums, it seems, will continue to be a feature of life for a minority of the population.

MIT robot gets a healing hand

Giving your limbs a good workout could soon take on a new meaning. Because engineers at the Massachusetts Institute of Technology (MIT) have developed a robot that can learn exercise routines from a physiotherapist and then go on to guide a patient through those same exercises. Uniquely, according to its developers, the robot can also record all the resulting biomechanical data and use it to make objective measurements of the patient's condition, together with his or her progress.

Professor Neville Hogan, leader of the team that developed the robot, says it will be used in clinical trials this Autumn on people who suffer mechanical deficits arising from strokes.

At present there is a great deal of debate over whether manual manipulation of stroke victims' limbs really helps them recover. The new robot has two properties that should help decide the matter once and for all. In the first place it can take the patient through a completely standardised exercise routine; secondly, it can monitor precisely the patient's response to that exercise.

The system can record exactly the amount of force a patient applies, the velocity of any movements and the absolute position of the limb at any moment in time. Normally, such movements can only be assessed qualitatively by touch and feel.

The robot, called 'Manus' (Latin for 'hand'), is decidedly user-friendly. As well as performing the basic mechanical functions, it also provides video games to hold a patient's attention during what can often be very monotonous exercises. The games correspond to a patient's performance at any given exercise and provide a visual clue that he or she is not pushing hard enough or pushing too hard. Four different games have been designed for patients at different levels of recovery.

As well as operating in its therapeutic mode, Manus could also become an important teaching tool. Professor Hogan suggests that it could be used to record the hand movements of a skilled doctor, surgeon or physiotherapist as that person manipulated a dummy (or even a real patient). A trainee could then repeat the exercise while the machine recorded every difference in detail. With a second slave machine, the "expert" could even feel directly what the trainee was doing – or not doing. And of course the slave machine could be thousands of miles away on the end of a data link.

Research Notes is written by John Wilson of the BBC World Service.
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Applied i/o for the PC

There are three main ways of controlling input/output devices from a PC. Via the Centronics printer port, via a dedicated i/o card or via the serial port. Although faster than the serial alternative, the Centronics port is difficult to read from and write to. It also has the drawback that it prohibits use of the printer.

A dedicated i/o card can be fast and inexpensive. However it takes up a slot and ties the interface card to one machine. Additionally, laptops have no card slots so the interface cannot easily be made portable. Input/output cards can also be inflexible, often requiring one card for each function.

Most PCs have two serial ports and one is usually free. The interface is well documented and programmable in a variety of languages. If correctly buffered, a serial interface also provides some immunity against power surges. In the event of an overload, the buffer chips will usually fail, leaving the PC intact.

Circuit description

Data to and from the serial line is buffered by IC3 of Fig. 1. Using a MAX232 minimises power supply requirements. From a single +5V rail, it produces the ±10V levels needed for correct RS232 transmission.

Serial data is converted to parallel bytes and vice versa by the universal asynchronous receiver/transmitter, IC4. Data bytes are buffered by IC5,6. To send data presented at the inputs to IC6 down the serial line, a negative pulse needs to be applied to the transmitter-buffer register load input, /TBRL, on pin 23. When a low level is applied to the pin, data present at TBR1_8 is transferred into the transmitter-buffer register. When the /TBRL goes high, data is transferred to the transmitter register from which it is transmitted serially.

Conversion of data from serial to parallel is equally straightforward. Whenever a byte of data arrives down the serial line, the data-received output, DR, goes high on pin 19. If this output is then inverted and fed into the data received reset, /DRR, on pin 18, the data-received output will be reset. In this case the inversion is carried out by a 74S109.

This arrangement means that multiple byte data can be sent down the serial line and the data-received output used to drive latches, etc. It also avoids wasting a data bit line.

Because all data in/out lines are terminated with 10KΩ pullup resistors, the length of ribbon cable that can be driven is approximately seven feet. Bit rate limits of the board are 600 and 76,800, although for 76,800 a special software communications library unit will be needed together with a faster uart in the host PC. One such device is the NS16550.

Serial input/output

Standard PCs have a set of bios routines that can be accessed by a high level language such as Pascal. These routines allow a maximum bit rate of 9600 baud, or 19,200 for the PS2. This means that you can output data in bytes at 960Hz, assuming one start bit, eight data bits, no parity, and 1 stop bit.

Digitisation is limited to half the rate of data output. This is because any a-to-d converter has to be triggered before it will convert, and the trigger signal usually comes down the serial line.

One way of increasing the data rate for a-to-d conversion is to send one trigger signal and then collect a predetermined number of data bytes. In this way data can be gathered in bursts interspersed with minimal gaps.

Programming

The kernel software Listing 1, shows the essential procedures that can be used to com-
Fig. 1. Advantages of interfacing a PC to i/o via the RS232 interface are numerous. Being external, a serially fed i/o card can be plugged easily from one PC to another. It provides some i/o fault immunity to the PC and software writing is easy. Achieving a high operating speed however involves very high serial communication rates.
municate with the board. The functions of bits in the MOV AL, 11100011B statement are:

<table>
<thead>
<tr>
<th>Bits</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>000 110 baud</td>
</tr>
<tr>
<td>6</td>
<td>001 150 baud</td>
</tr>
<tr>
<td>5</td>
<td>010 300 baud</td>
</tr>
<tr>
<td>4</td>
<td>011 600 baud</td>
</tr>
<tr>
<td>3</td>
<td>100 1200 baud</td>
</tr>
<tr>
<td>2</td>
<td>101 2400 baud</td>
</tr>
<tr>
<td>1</td>
<td>110 4800 baud</td>
</tr>
<tr>
<td>0</td>
<td>111 9600 baud</td>
</tr>
<tr>
<td></td>
<td>00 no parity</td>
</tr>
<tr>
<td></td>
<td>01 odd parity</td>
</tr>
<tr>
<td></td>
<td>10 no parity</td>
</tr>
<tr>
<td></td>
<td>11 even parity</td>
</tr>
<tr>
<td></td>
<td>0 1 stop bit</td>
</tr>
<tr>
<td></td>
<td>1 2 stop bits</td>
</tr>
<tr>
<td></td>
<td>10 7 bit word length</td>
</tr>
<tr>
<td></td>
<td>11 8 bit word length</td>
</tr>
</tbody>
</table>

A-to-d conversion

Figure 2 shows the circuit diagram of an a-to-d converter with associated circuitry for digitising light intensity. Whenever a byte of data from the host computer is sent down the serial line, a brief positive pulse is sent out from the RS232 board. This is used to trigger the a-to-d converter.

When conversion is complete, the INT line output of the a-to-d fires the 74121 monostable. This in turn provides the negative pulse to the board which then sends the data to the host.

The op-amps are single supply rail types. If a photodarlington transistor is used then problems will occur due to the high sensitivity of the device. This will make it difficult to obtain a linear response from dark to light.

I have tried the circuit with a few different types of photo-transistor and without problems. Even a BC1D9 with its top cut off produced acceptable results, although the 10kΩ potentiometer in Fig. 2 had to be replaced a 1MΩ type.

Listing 2 shows a program fragment using the routines of the kernel listing to communicate with the board and take data from the a-to-d.

Hardware/software availability

A fully populated board following the RS232 interface circuit in this article can be obtained from B. Teleki, 8 Victoria Court, Brampton Road, Maybank, Newcastle-Under-Lyme, Staffordshire ST5 0SL, Tel. 0782 662099 after 6pm. Its cost is £89, including software, postage and VAT. The board has a 5cm by 7cm prototyping area and all i/o lines are available via a 40-way IDC header. This offer is made in good faith, but please note that EWW&W has no involvement in it and therefore cannot accept responsibility for any problems that may arise relating to transactions between Mr Teliki and readers.

Listing 1. Kernel routine in Pascal for communicating with the PC i/o card over an RS 232 link.

```
PROGRAM SERIAL (INPUT,OUTPUT);
USES
DOS,CRT;
VAR
BYTE_RCVD : BYTE;
DATA,RT_CD : BYTE;
PROCEDURE INIT_COM;
BEGIN
   ASM
      MOV AL,11100011B;  \{9600 BAUD, 8 BITS, NO PARITY, 1 STOP BIT.\}
      MOV DX,1;        \{0=COM1, 1=COM2, 2=COM3, 3=COM4\}
      MOV AH,0;        \{SPECIFY SERVICE 0\}
      INT 14H;         \{BIOS COMM, INTERRUPT\}
   END;
PROCEDURE SEND_BYTE(BYTE_TO_SEND:BYTE);
BEGIN
   ASM
      MOV AL,BYTE_TO_SEND;  \{SPEC THE BYTE\}
      MOV DX,1;            \{SET COM2\}
      MOV AH,1;            \{SPECIFY SERVICE 1\}
      INT 14H;             \{BIOS COMM, INTERRUPT\}
   END;
PROCEDURE GET_BYTE;
BEGIN
   ASM
      MOV AL,0;            \{CLEAR AL\}
      MOV DX,1;            \{SET COM2\}
      MOV AH,2;            \{SPECIFY SERVICE 2\}
      INT 14H;             \{BIOS COMM, INTERRUPT\}
      MOV BYTE_RCVD,AL;   \{PUT THE BYTE INTO BYTE_RCVD\}
   END;
PROCEDURE QUIT_COM;
BEGIN
   ASM
      MOV RT_CD,AL;       \{RETURN CODE :: LOOK AT IF SOMETHING WRONG\}
      MOV AH,4CH;         \{CLEAN UP AFTER FINISHED\}
      INT 21H;            \{DOS SERVICES INTERRUPT\}
   END;
BEGIN
   INIT_COM;
   (SEND DATA AND/OR GET DATA USING SEND_BYTE AND GET_BYTE)
   QUIT_COM;
END.
```
Figure 2. Measuring light intensity via a PC. A-to-d conversion of light intensity to 8 bits provides a theoretical dynamic range of 48dB. More elaborate biasing around the opto transistor could improve this.

Figure 3 shows a ZN429E d-to-a converter driving a VFET for high power. Depending on the output data rate and application, an interpolation filter may be required.

Replacing the loudspeaker with a dc motor needs a diode in parallel with the motor to prevent back emf damaging the driving circuitry. A 1N4001 with its cathode connected to the positive rail should suffice. Listing 3(b) shows how the motor can be accelerated up to maximum speed, held there a moment, and then decelerated.

Controlling a stepper motor
Figure 4 shows a high-power stepping motor interface and Listing 4 its driver software. Since the motor in this example is a four-phase type requiring a ring counter sequence, binary values of each step have to be converted to decimal numbers before transmission. A value of 11002 for example represents 12, value 01101 is 6, 00112 is 3 and 10012 is 9.

Pascal background
Pascal is a procedural language, which means that all functions are first declared as procedures and then called up at the end of the program.

For example:

```
PROGRAM TEST;
USES DOS, CRT, PRINTER, GRAPH;
VAR
  A, B, C, D : REAL;
PROCEDURE BLAH(E:REAL;VAR F: REAL);
    BEGIN
      F := E/2;
    END;
PROCEDURE STUFF(ZARQ, BLARQ :REAL; VAR RESULT :REAL);
    BEGIN
      RESULT := SQRT(SQR(ZARQ) + SQR(BLARQ));
    END;
BEGIN
  WRITE('VALUE OF A, B = ?');
  READLN(A, B);
  BLAH(A, C);
  STUFF(B, C, D);
  WRITE('VALUE OF PARAMETER =', D);
END.
```

The USES statement calls up various inbuilt library units to do standard operations. DOS is a unit that allows you to invoke dos calls such as GETTIME, SETTIME, DISKSIZE, etc. Unit CRT manipulates text screens and controls sound while PRINTER enables you to output to the printer.

GRAPH is for Hercules to VGA graphics functions. Declaration VAR defines the global variables you are to use and their types. The PROCEDURE statement allows you to group a sequence of operations into one self contained sub program. When declaring a procedure, local incoming variables are declared first, together with their types and then the outgoing variables, preceded by the word VAR.

Pascal also has the capability of being extended. For example if your version doesn't have a complex maths library unit, it is fairly easy to write the unit that performs the complex maths. When it is compiled, you have all the types and operations available in your program that were declared in the unit. You simply add COMPLEXMATH to the USES clause at the top of the program.

It is also possible to put assembler statements into a procedure, as in the kernel listing, so that hardware can be directly controlled.
Image acquisition

With a dot-matrix printer that can emulate the standard IBM printer graphics mode, it is possible to make the printhead scan across any hard-copy image in the printer’s paper path. Most dot-matrix printers can emulate the IBM graphics mode.

By attaching one end of an optical fibre to the print head and the other end to the opto-transistor shown in Fig. 2, it is possible to read a bit-map of the image passing the print head into the PC. An example of the reproduction obtainable via this method is the photograph of Bogart on the front cover of the magazine.

A light source is needed for this application, usually positioned about 300 to 600mm away and to the side of the printer. Listing 5 shows the procedure that controls the printer and acquires the data from the a-to-d converter.

Because the data length of the printer in the selected mode is 960 bytes and resolution of a VGA screen is 640-pixel, line-scan is not 100% straightforward. One byte of data is sent to the printer on the odd count and two bytes on the even count. After each data transmission moves the head, the image light level is sampled.

Resolution attainable is approximately 80 dots per inch. Epson and IBM type printers also have a 480-byte line mode but it produces very poor scans. The software that does the scanning redefines the VGA palette to 16 grey shades and brackets the 256 levels that come from the a-to-d to one of these shades. Images are saved in standard paintbrush (.PCX) format with palette information.

Windows quite happily accepts the image, as long as it is in a 256 colour mode or higher. If in sixteen colour mode, Windows will remap the incoming palette to its own colour set and the result will make you want to go for a quiet lie down somewhere.

Due to the large 1mm diameter of the optical fibre – the cheapest I could find – sampling problem occurs due to aliasing. To be precise, the problem is spatial aliasing caused by the relatively large diameter of the optical fibre compared to the resolution of the printer. As the fibre scans across an image, the sample points are slightly overlapped which results in some of the data from one sample point appearing in the next. This means that dark striations appear on the scanned image.

However with the use of some filtering software the interference can be removed. A line-array ccd could produce much better results.

Temperature measurement

By using a diode – 1N4148 will do – and a 1kΩ series resistor instead of the opto-transistor and 3kΩ resistor of Fig. 2, a reasonably

Continued on page 458
Listing 5. Image scanning with the aid of a dot-matrix printer involves moving the head across the image and sampling light level at each increment. In the variable declaration, stuff is declared as type TEXT; later on in the program assign it to the printer port with ASSIGN(STUFF,'LPT1').

PROCEDURE SCAN; {FULL PAGE SCAN; EQUIV TO APPROX 80 DPI}
BEGIN
  WRITE(STUFF,#27,#60); {RESET PRINTER}
  WRITE(STUFF,#27,#85,#1); {UNIDIRECTIONAL PRINTING}
FOR X := 0 TO 639 DO
BEGIN
  WRITE(STUFF,#27,#51,#03); {MOVE PAPER BY 3/216 INCH}
  WRITE(STUFF,#27,#76,#192,#3); {SLOW MODE = 460 DOTS/SCAN RES}
  FOR Y := 0 TO 479 DO
BEGIN
    IF ODD (X) THEN
    BEGIN
      WRITE(STUFF, #00); DATAGET;
    END
    ELSE
    BEGIN
      WRITE(STUFF,#00,#00); DATAGET;
    END;
    IF KEYPRESSED = TRUE THEN
    BEGIN
      X := 639;
      Y := 479;
    END;
  END;
END;
END;

Listing 6. Routines for plotting temperature against time.

PROCEDURE SETUPGRAPHICS;
BEGIN
  GD := DETECT; INITGRAPH(GD,GM,''); {INITIALISE GRAPHICS SYSTEM}
  IF GRAPHRESULT <> GROK THEN {ALL SCREEN OUTPUT ASSUMES THAT)
    HALT(1); {A VGA ADAPTER IS PRESENT}
  SETVIEWPORT(0,0,GETMAXX,GETMAXY,CLIPON);
  SETWRITEMODE(OUTPUT);
  SETCOLOR(15);
  RECTANGLE(0,0,639,240);
  LINE(0,15,639,15);
  SETTEXTJUSTIFY(LEFTTEXT,CENTERTEXT);
  SETTEXTSTYLE(DEFAULTFONT,HORIZDIR,1);
  OUTTEXTXY(240,09,'TEMPERATURE MEASUREMENT'); {PUT TITLE AT TOP OF SCREEN}
  K := 0;
  REPEAT
    LINE(K,15,K,240);
    STR(K*30,SCREENTEXT);
    OUTTEXTXY(K+2,235,SCREENTEXT+'ms'); {PUT TIMING TICKS ON X AXIS}
    INC(K,64);
  UNTIL (K>639);
END;

BEGIN
  SETUPGRAPHICS;
  INIT_COM2;
  FOR K := 1 TO GETMAXX DO
BEGIN
  SEND_BYTE(0); {START CONVERSION}
  GET_BYTE; {GET THE DATA}
  PUTPIXEL(K,3*BYTE_RCVD-200,15); {PLOT DATA WITH SCALING AND OFFSET}
  DELAY(30); {WAIT FOR 30ms}
END;
CLOSEGRAPH;
END.

ADC0804 a-to-d converter
This converter is suitable for both microprocessor bus based systems and stand-alone a-to-d applications. Its conversion time of 100ms limits its use to audio frequencies and below.

Low speed is offset by the device's cheapness - at around £4.25 - and ease of use. Its on-board clock generator needs only two external components. As you can see from Fig. 1, driving the device is straightforward.

With a single 5V supply and 2.5V applied to \( V_{ref} \), the analog input voltage range is 0 to 5V. Fig. 2 uses a forward biased diode to provide the reference voltage of 0.7V which leads to an input voltage range of 0 to 1.4V.

Voltage reference \( V_{ref} \) can be any value under 2.5V. As a result, any voltage span can be converted with a full eight bits of resolution. Also, by connecting \( -V_o \) to a voltage other than ground (note the 1kΩ pot in Fig. 2) the voltage conversion range need not start at 0V.

Stepping motor background
Consider the simplified diagram of the typical stepping motor shown below with windings A to D. The armature is a cylindrical magnet with poles N and S.

Applying a voltage to phases A and B results in the poles of the motor armature aligning with the two phases in an orientation depending on the polarity of the applied signal.

If phase A is switched off and phase C switched on while B is still on, the motor armature realigns itself with the new phase. Similarly if B is switched off and D on, the armature again aligns itself with the new phase. In this way the motor rotates.

Excitation sequence is AB, BC, CD, DA, AB. In practice the phases are wound with higher multiples of each other so that the step angle is much less. A typical example is 200 steps per revolution, which is equivalent to 1.8° per step.

It is possible to double the resolution of a stepping motor by half stepping it. Instead of exciting it as in the above sequence, if the following sequence A, AB, B, BC, C, CD, D, DA, A is fed to the motor, then 400 steps per revolution will result.

Stepping motors are found in plotters, floppy disk drives, hard disk drives, pick and place machinery and sewing machines. They are extensively used in industry, particularly for robotic manipulators.
accurate measurement of temperature can be made. The configuration is the same as the diode resistor combination that provides the 0.7V reference.

This arrangement ignores the non-linear temperature dependence of the pn junction but at 5p each as opposed to £1.20 for the LM335Z or £3.45 for the LM35DZ, a degree of non-linearity is a small penalty. Note that the temperature sensing diode is followed by a gain block to amplify its approximate -2mV/°C to a level that the a-to-d converter can handle.

You may have noticed that the circuit uses a diode to provide a reference voltage to the a-to-d converter. This will always be at the local ambient temperature, so its voltage variation is going to be relatively small compared to the amplified voltage of the temperature sensing diode.

Listing 6 shows routines for plotting temperature against time. Figure 5 is a typical temperature plot against time. The 0°C point was measured by putting the diode into melting ice, while the 80°C point was obtained by putting the diode into a convenient cup of hot tea.

For a faster data acquisition rate, the DELAY(30) (30ms delay) command can be removed from the listing.

References
1. Jourdain, R., Programmer’s problem solver for the IBM PC, XT & AT, Brady.
4. 6402 Data sheet.

PCBs for Douglas Self’s power amplifier series

Circuit boards for Douglas Self’s high-performance power amplifier are now available via EW+WW.

Detailed on page 139 of the February issue, Douglas Self’s state-of-the-art power amplifier is the culmination of ideas from one of the most detailed studies of power amplifier design ever published in a monthly magazine. Capable of delivering up to 100W into 8Ω, the amplifier features a distortion figure of 0.0015% at 50W and is designed around a new approach to feedback.

Designed by Douglas himself, the fibreglass boards have silk-screened component IDs and solder masking to minimise the possibility of shorts. Sold in pairs, the boards are supplied with additional detailed constructional notes.

Each board pair costs £45, which includes VAT and postage, UK and overseas. Credit card orders can be placed 24 hours on 081 652 8956.

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ELECTRONICS WORLD+WIRELESS WORLD June 1994
From humble beginnings, the PC has grown into one of the world's most widely used office machines. David Guest encapsulates the PC's history and takes a brief look at its architecture.

Early computers - mainframes - interfaced to numerous terminals comprising a keyboard and monitor. Combined with a multitasking operating system, this allowed a number of users to access the same computer simultaneously. Only large companies and research establishments could justify the high capital and subsequent maintenance costs.

In 1971 Intel released its first microprocessor - the 4-bit 4004 - developed for a calculator company called Busicom.

Further development resulted in the first 8-bit processor, the 8080, which ultimately led to the manufacture of the well-known 8080 processor in 1973.

Initially, the 8080 was used for video games. It eventually devolved into a computer available in kit form only - the Altair - with a hex keypad and LED display. It was not until two further breakthroughs that the 8080 microprocessor found its way into business applications. These were development of the CP/M operating system by Gary Kildall, founder of Digital Research, and invention of the floppy disk for data storage by John Torode.

Computing machines adapted quickly, as did spreadsheet and word processing type software. By now, other microprocessor manufacturers had introduced their own devices. The most common of these was the Motorola 6800, adopted for Apple's range of computers.

From 1976, a vast variety of computers were introduced, the main core being aimed primarily at video games for the domestic market. Due to their lack of serious software however, CP/M based systems continued to dominate the business sector.

In 1979, Intel brought out the first 16-bit processor - the 8086. This device could handle 16-bit data but, more significantly, it could address up to 1Mbyte of memory. This overcame the serious restrictions of the 64Kbyte limit imposed by existing 8-bit alternatives. Due to manufacturing problems and cost considerations, the 8086 was modified to support an 8-bit external data bus. Called the 8088, the new device maintained a true 16-bit core and 1Mbyte addressing capability.

At this time Motorola had not yet developed its 16-bit 68000 series microprocessors. Intel, as a result, had a market edge, which ultimately led to IBM selecting the Intel processor and associated support chips for the IBM PC, launched in 1981.

The disk operating system associated with the PC - originally PC-DOS - rapidly became an industry standard. In the same way that CP/M systems had brought about the standardisation of 8in floppy-disk drives, DOS caused the standardisation of their 5.25in successors. The overnight success of the PC surprised everyone, even IBM, spurring them to release the PC-XT at the end of 1982. As standard, the XT had 64Kbyte of memory and a 10Mbyte hard disk drive, providing rapid access to frequently used software.

Subsequent release of the PC jr, more commonly known as the Peanut, saw IBM fail in an attempt to gain access to the small business and domestic market. Poor quality keyboard and disk drive problems, together with a high cost compared to other machines in the sector, caused the Peanut's withdrawal from the market in 1985.

Released in 1984, the high end PC-AT was more successful. It performed between five and six times faster than the PC-XT, and had 512Kbyte of memory and a 20Mbyte hard disk drive as standard. Contrary to IBM's belief that the PC-AT would be used to run multitasking UNIX based operating systems, it was bought mainly as a means of running DOS software more quickly.

Popularity of the PC attracted other manufacturers. They responded by producing cheaper PCs - or clones - with improved specifications. The first of these to gain wide acceptance was the Olivetti M24.
Intel recently released the Pentium. This chip found its way into the high end of the market, coprocessor on a single chip. This device has processor, memory cacheing and a maths and developed an optimised 386DX processor. took the lead in the early 1990s.ing popularity of software and the falling price 32-bit core of the 80386DX. Due to the grow-

In 1986, Intel launched the 32-bit 80386DX featuring a 4Gbyte memory addressing capa-

A cheaper version of the 80386 was soon relea-

intel continued to improve its technology and developed an optimised 386DX processor. Called the 80486DX, it combined the main processor, memory caching and a maths coprocessor on a single chip. This device has found its way into the high end of the market, used for CAD and similar systems. Building on the performance of the 80486, Intel recently released the Pentium. This chip has received mixed reviews in the press. It requires recompilation of existing PC software source code to take full advantage of its enhanced capabilities.

Inside the PC

As illustrated in Fig. 1, the original PC-XT architecture was built around Intel's support chips developed for 8086/8088 based processor systems. Most of these devices are pro-

There were no facilities on the processor for accessing to 1Mbyte memory directly. The 80286 failed in this area, but 80386 introduced new features such as virtual memory and multitasking. These capabilities allowed applications to run in any 1Mbyte window of the system memory.

Timer zero of the 8254 generates eight system timer interrupts via an 8259A programmable interrupt controller. These maintain the system clock, keyboard and I/O slot cards. Direct memory access is under control of timer one. An additional three interrupts are produced by the DMA chip for use by I/O

<table>
<thead>
<tr>
<th>I/O address (hex)</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>000-00F</td>
<td>8237 DMA #1</td>
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<tr>
<td>020-021</td>
<td>8259 PIC #1</td>
</tr>
<tr>
<td>040-043</td>
<td>8233 CTC</td>
</tr>
<tr>
<td>060-063</td>
<td>8255 PIO (XT)</td>
</tr>
<tr>
<td>080-086</td>
<td>8742 Keyboard I/F (AT)</td>
</tr>
<tr>
<td>070-071</td>
<td>CMOS RAM &amp; NMI Mask (AT)</td>
</tr>
<tr>
<td>080-08F</td>
<td>DMA Page Registers</td>
</tr>
<tr>
<td>0A0-0A1</td>
<td>8259 PIC #2 (AT)</td>
</tr>
<tr>
<td>0A0-0AF</td>
<td>NMI Mask Register (XT)</td>
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<tr>
<td>0CC-0DF</td>
<td>8237 DMA #2 (AT)</td>
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<tr>
<td>0F0-0FF</td>
<td>8237 CoProcessor (AT)</td>
</tr>
<tr>
<td>1F0-1FF</td>
<td>Hard disk (AT)</td>
</tr>
<tr>
<td>200-20F</td>
<td>Game/Controller</td>
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<tr>
<td>210-21F</td>
<td>Expansion Unit (XT)</td>
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<tr>
<td>238-23B</td>
<td>Bus Mouse</td>
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<tr>
<td>23C-23F</td>
<td>Alt Bus Mouse</td>
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<tr>
<td>278-27F</td>
<td>Parallel Printer (LPT3)</td>
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<tr>
<td>280-28F</td>
<td>EGA</td>
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<td>EGA</td>
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<td>310-31F</td>
<td>Prototype Card</td>
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<td>Hard Disk (XT)</td>
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<td>Parallel Printer (LPT2)</td>
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<td>3BC-3BF</td>
<td>Parallel Printer (LPT1)</td>
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<td>3D0-3DF</td>
<td>CGA</td>
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<tr>
<td>3EE-3EF</td>
<td>Serial Port (COM3)</td>
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<tr>
<td>3F0-3F7</td>
<td>Floppy Disk</td>
</tr>
<tr>
<td>3F8-3FF</td>
<td>Serial Port (COM1)</td>
</tr>
</tbody>
</table>

Extended memory, XMS

Launch of the AT coincided with the introduction of processors capable of accessing memory above 1Mbyte. However, the so-called 'extended' memory could only be accessed with the processor running in protected mode.

Extended memory area was not maintained by DOS, requiring the introduction of the extended memory driver HIMEM.SYS. This driver gave a well defined interface to DOS based software, providing access to memory above the 1Mbyte boundary. In addition, HIMEM.SYS controls gating of the A20 address line, providing DOS based software with access to the first 64Kbyte of extended memory as part of the real-mode memory map. As a result, there is access to 1024Kbyte even though 1Mbyte is only 1024Kbyte.

The extra memory space is achieved by a quirk of the 8086 family address mechanism whereby addresses are offset by a segment register. If the register is loaded with values above FFFF16, the resulting memory address exceeds the 1Mbyte limit.

External hardware is needed to gate the processor A20 signal, controlled by HIMEM.SYS. For 8086 and later processors, the expanded memory driver uses the HIMEM.SYS driver to allocate system memory above 1Kbyte for use as extended memory.

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**Table 1. I/O map for the XT and AT.**

**I/O address (hex) | Usage**
<table>
<thead>
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<td>MDA</td>
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<td>Parallel Printer (LPT1)</td>
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</tr>
</tbody>
</table>
slots. Interrupts for the 8255A programmable parallel interface are derived from timer two. This chip adapts counter two output to produce audio output from the speaker. The parallel interface chip also connects to the keyboard and gives the processor access to a range of status and control lines in the system. Interfaces to communications ports and storage media, such as floppy and hard disk drives, had well defined positions within the architecture. They had specific I/O addresses, Table 1, and interrupt or DMA channels Table 2. Since only the lower ten address lines on the original peripheral cards were decoded, the address map has become overcrowded. This forces I/O devices to reside exclusively in the first 1 Kbyte of I/O space, instead of in the full 64 Kbyte supported by the processor.

Interfacing to the graphics display has evolved alongside display adapters. Features and resolutions have been extended while maintaining compatibility with the original monochrome display adapter, MDA, add-on card released with the original PC.

The first graphics card was the Hercules. It added 720 by 350 pixel graphics on to the 80-column by 25-line text only potential of the MDA card. Soon after came the colour-graphics adapter, or CGA standard, which supported two colours with a resolution of 640 by 200 pixels, or four colours at a resolution of 320 by 200.

Graphics resolution was further extended with the enhanced graphics adapter, or EGA, which supported 16 colours at resolutions up to 640 by 350. It is now superseded by the video graphics array standard, VGA, offering up to 720 by 400 pixels in text mode or 16 colours at 640 by 480 for graphics. Super VGA extends this capability even further and state-of-the-art graphics cards are now capable of 1280 by 1024 pixels with 16.7 million colours.

**AT architecture**

Architecture of the AT contained features of

| Table 2. Hardware interrupts and dma channels. |
|-----------------|-----------------|
| **IRQ Level**   | **Use**         |
| (XT and AT)     |                 |
| NMI             | Parity          |
| IRQ0            | System Timer    |
| IRQ1            | Keyboard        |
| IRQ2            | Cascade for IRQ8-15 |
| IRQ3            | COM2            |
| IRQ4            | COM1            |
| IRQ5            | Hard disk(XT)/LPT2(AT) |
| IRQ6            | Floppy Disk     |
| IRQ7            | LPT1            |
| **(AT only)**   |                 |
| IRQ8            | Real Time Clock |
| IRQ9            | Re-directed to IRQ2 |
| IRQ10           | Unassigned      |
| IRQ11           | Unassigned      |
| IRQ12           | Unassigned      |
| IRQ13           | 80287 Co-processor |
| IRQ14           | Hard Disk       |
| IRQ15           | Unassigned      |

**DMA channel**

<table>
<thead>
<tr>
<th>Use, 8-bit transfers</th>
<th>(XT and AT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMA0</td>
<td>Memory Refresh</td>
</tr>
<tr>
<td>DMA1</td>
<td>SDLC</td>
</tr>
<tr>
<td>DMA2</td>
<td>Floppy Disk</td>
</tr>
<tr>
<td>DMA3</td>
<td>Unassigned</td>
</tr>
</tbody>
</table>

**DMA channel**

<table>
<thead>
<tr>
<th>Use, 16-bit transfers</th>
<th>(AT only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMA4</td>
<td>Unassigned</td>
</tr>
<tr>
<td>DMA5</td>
<td>Unassigned</td>
</tr>
<tr>
<td>DMA6</td>
<td>Unassigned</td>
</tr>
<tr>
<td>DMA7</td>
<td>Unassigned</td>
</tr>
</tbody>
</table>

Continued on page 465

**Fig. 2. A significant advance on the XT, the PC AT had a fully 16-bit processor and additional DMA capability. Unlike the XT, the AT also had the ability to date-stamp files from real-time clock information.**
PC memory map

To avoid the dependency of software on hardware configurations, a standardised basic I/O system, or BIOS, was developed. In attempts to speed up their programs however, many writers produced software that communicated directly with I/O, bypassing the BIOS. As a result, future PC designs had to maintain hardware compatibility to maximise the usefulness of existing software.

In the original PC, 640Kbyte of memory was reserved for use by the operating system and programs while the area between 640Kbyte and 1Mbyte catered for the video adapter and other add-on cards. Most 8086 based computers supported a minimum of 1Mbyte of memory in the area above 640K. This memory occupied the same address space as the BIOS ROMs and video memory.

Originally, the BIOS and video memory area was only used for shadowing the BIOS ROMs to improve system performance. Software, like QEMM by Quarterdeck, and more recently DOS 5, makes use of this area of memory available to DOS programs, freeing up the valuable 640K of DOS memory for use by software applications. Using a technique that pages out and relocates memory interactively, QEMM goes a step further than DOS. Even with DOS taking advantage of High Memory and the Upper Memory Area, it still takes memory in the lower 640Kbyte of memory space, Table 3.

The first kilobyte of memory stores the interrupt vector table for redirecting software interrupts to the necessary software routines. The following 256 bytes is the BIOS data area that provides information on the system architecture and parameters related to BIOS calls, Table 4. DOS reserves the next 512 bytes, called the DOS communication area, for its own use. Immediately following this is the DOS kernel, i.e., the hidden IO.SYS and MSDOS.SYS files, and the internal DOS drivers. Then come the drivers that relate to entries in the CONFIG.SYS file. Device drivers appear first, followed by memory areas for file handles, disk buffers, stacks and so on. Remaining memory is used by programs, the first always being the part of COMMAND.COM, known as the resident portion. Remaining space is filled by terminate and stay resident programs, or TSRs, that always remain in memory and by any program being executed.

Expanded memory, EMS

When the PC became available, memory access capability rose from the 64Kbyte possible with 8-bit microprocessors to a relatively massive 1Mbyte. However, this rapidly became inadequate due to the increasing complexity of software and its associated data.

In response, Lotus, Intel and Microsoft initiated a joint venture to overcome the 1Mbyte limit imposed by PC-XT 8088/8086 processors. They introduced the expanded memory specification called LIM EMS 3.0.

This standard provided DOS with up to 8Mbyte of additional memory, resident on a plug-in I/O card. The memory was organised as banks of 16Kbyte pages. Four of these could reside in the DOS memory map at a time, typically from D0000 to DFFFF. Banks could be selected via hardware registers, accessed via an expanded memory driver.

Development of the AT computer with its 16Mbyte of memory was expected to see the demise of the requirement for expanded memory. Loyalty to DOS by most PC users however meant that this extra memory could not be accessed by programs.

Software running under DOS cannot take advantage of the memory management unit made available in the later processors. They only execute in real mode, preventing access to memory beyond the 1Mbyte boundary. For this reason EMS was still extensively used; however, introduction of the 80386 processor with its sophisticated internal memory management unit removed the need for external hardware for bank switching.

In revision 4.0, the EMM system driver was redefined to take advantage of bank switching. It made use of system memory above 1Mbyte, allowing DOS based programs access to extended memory. The driver's implementation of extended memory makes it dependent on the extended memory driver, HIMEM.SYS. This driver must always be loaded prior to the expanded memory driver, EMM386.EXE. Version 5 of DOS also needs the expanded memory driver in order to make use of the upper memory area between 640Kbyte and 1Mbyte. This area is normally associated with the system BIOS and the video driver.

Table 3. The computer's memory map.

<table>
<thead>
<tr>
<th>Available memory</th>
<th>Top of memory to</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td>FF000h</td>
</tr>
<tr>
<td>Resident portion of command.com</td>
<td></td>
</tr>
<tr>
<td>DOS config.sys entries</td>
<td>60000h</td>
</tr>
<tr>
<td>DOS kernel and internal device drivers</td>
<td>600FFh</td>
</tr>
<tr>
<td>DOS communication area</td>
<td>60200h</td>
</tr>
<tr>
<td>ROM expansion area (256 bytes)</td>
<td>60400h</td>
</tr>
<tr>
<td>.</td>
<td>604FFh</td>
</tr>
<tr>
<td>BIOS stack/user vectors (256 bytes)</td>
<td>60600h</td>
</tr>
<tr>
<td>User vectors (256 bytes)</td>
<td>60640h</td>
</tr>
<tr>
<td>Interrupt vectors (480 bytes)</td>
<td>60700h</td>
</tr>
<tr>
<td>...</td>
<td>FFFFh</td>
</tr>
</tbody>
</table>

Fig. 3. Allowing up to 8Mbyte of pagged memory, expanded memory concept was developed to counter the 1Mbyte addressing limitation of earlier PCs.
### Table 4. PC interrupt vectors and their uses.

<table>
<thead>
<tr>
<th>Interrupt</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>00H</td>
<td>Hardware divide by zero</td>
</tr>
<tr>
<td>01H</td>
<td>Hardware single step strap</td>
</tr>
<tr>
<td>02H</td>
<td>Nonmaskable interrupt</td>
</tr>
<tr>
<td>03H</td>
<td>Debugger breakpoint set</td>
</tr>
<tr>
<td>04H</td>
<td>Arithmetic overflow</td>
</tr>
<tr>
<td>05H</td>
<td>BIOS print screen</td>
</tr>
<tr>
<td>06H</td>
<td>IRQ0 clock tick</td>
</tr>
<tr>
<td>09H</td>
<td>IRQ1 keyboard</td>
</tr>
<tr>
<td>0AH</td>
<td>IRQ2</td>
</tr>
<tr>
<td>0BH</td>
<td>IRQ3 COM2</td>
</tr>
<tr>
<td>0CH</td>
<td>IRQ4 COM1</td>
</tr>
<tr>
<td>0DH</td>
<td>IRQ5 PC/XT hard disk or PC/AT</td>
</tr>
<tr>
<td>0EH</td>
<td>IRQ6 Diskette</td>
</tr>
<tr>
<td>0FH</td>
<td>IRQ7 LPT2</td>
</tr>
<tr>
<td>10H</td>
<td>BIOS video services</td>
</tr>
<tr>
<td>11H</td>
<td>BIOS equipment list service</td>
</tr>
<tr>
<td>12H</td>
<td>BIOS memory size service</td>
</tr>
<tr>
<td>13H</td>
<td>BIOS disk services</td>
</tr>
<tr>
<td>14H</td>
<td>BIOS communication services</td>
</tr>
<tr>
<td>15H</td>
<td>BIOS miscellaneous services</td>
</tr>
<tr>
<td>16H</td>
<td>BIOS keyboard services</td>
</tr>
<tr>
<td>17H</td>
<td>BIOS printer services</td>
</tr>
<tr>
<td>18H</td>
<td>Invoke ROM-BASIC</td>
</tr>
<tr>
<td>19H</td>
<td>System reboot</td>
</tr>
<tr>
<td>1AH</td>
<td>BIOS time-of-day services</td>
</tr>
<tr>
<td>1BH</td>
<td>CTRL BREAK handler</td>
</tr>
<tr>
<td>1CH</td>
<td>Called by int 08H handler</td>
</tr>
<tr>
<td>1DH</td>
<td>Video parameter table</td>
</tr>
<tr>
<td>1EH</td>
<td>Disk parameter table</td>
</tr>
<tr>
<td>1FH</td>
<td>Graphics character table</td>
</tr>
<tr>
<td>20H</td>
<td>DOS terminator program</td>
</tr>
<tr>
<td>21H</td>
<td>DOS system services</td>
</tr>
<tr>
<td>22H</td>
<td>Program terminate</td>
</tr>
<tr>
<td>23H</td>
<td>DOS CTRL/BREAK</td>
</tr>
<tr>
<td>24H</td>
<td>DOS critical-error handler</td>
</tr>
<tr>
<td>25H</td>
<td>DCS disk read</td>
</tr>
<tr>
<td>26H</td>
<td>DCS disk write</td>
</tr>
<tr>
<td>26H</td>
<td>DCS terminate resident</td>
</tr>
<tr>
<td>27H</td>
<td>DCS disk read</td>
</tr>
<tr>
<td>28H</td>
<td>DC-S fast pulchur</td>
</tr>
<tr>
<td>29H</td>
<td>MS-NET services</td>
</tr>
<tr>
<td>2AH</td>
<td>DOS primary shell program loader</td>
</tr>
<tr>
<td>2EH</td>
<td>DOS multiplex interrupt</td>
</tr>
<tr>
<td>2FH</td>
<td>Mouse services</td>
</tr>
<tr>
<td>31H</td>
<td>Diskette vector if hard disk present</td>
</tr>
<tr>
<td>40H</td>
<td>Hard disk parameter table</td>
</tr>
<tr>
<td>41H</td>
<td>EGA BIOS redirection</td>
</tr>
<tr>
<td>42H</td>
<td>EGA parameter table</td>
</tr>
<tr>
<td>43H</td>
<td>EGA character table</td>
</tr>
<tr>
<td>44H</td>
<td>PC/AT Int 70H alarm</td>
</tr>
<tr>
<td>50H</td>
<td>NetI/O services</td>
</tr>
<tr>
<td>67H</td>
<td>EMS</td>
</tr>
<tr>
<td>70H</td>
<td>IF Q6 PC/AT real-time clock</td>
</tr>
<tr>
<td>71H</td>
<td>IF Q9 PC/AT redirect of Int 0AH</td>
</tr>
<tr>
<td>75H</td>
<td>IF/Q3 PC/AT match coprocessor</td>
</tr>
</tbody>
</table>

**System 200 Device Programmer**

**System:** Programs 24, 28, 32 pin EPROMS, EEPROMS, FLASH and Emulators as standard, quickly, reliably and at low cost.

Expandable to cover virtually any programmable part including serial EEPROMs, PALs, GALs, EPLDs and microcontrollers, in many different packages.

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**Further Reading**


To contact someone on the telephone network, you dial their telephone number. With mobile radio, that initial contact is not so easy. Signalling protocols have evolved which allow selective calling. Communications engineer James Vincent explains the design considerations.

The simplest way of trying to contact a specific radio user is to make the initial call on either the channel in use or on a predetermined calling channel. This procedure is fine if the frequency is relatively clear and the users well disciplined. However on a crowded radio channel even radio discipline cannot ensure that the initial call will get through.

With the increasing demand for radio spectrum, techniques such as digital modulation, spread spectrum and amplitude companded single sideband are being employed to increase channel capacity. Unfortunately the majority of these techniques are not backward compatible with the hardware already in use, such as conventional narrowband am and fm systems. Often the considerable investment in the system infrastructure limits the options available.

The simplest approach to increasing the efficiency of a radio communication system is to use special signals to call selectively a particular user or user group. Such techniques are called ‘selective calling’ or selcall.

Selcall techniques

Single toneburst. The simplest selective call system is based around a single audio tone which, when transmitted, causes a tone detector in the receiver to unmute and enable the audio output (this can be as simple as connecting the loudspeaker). Although simple, it carries significant disadvantages: Only tones within the audio passband of the radio system can be used. This limits the number of tones which can be used and hence the number of stations that can be called; Most tone decoders can only reliably decode tones which have an adequate frequency separation. This results in the creation of guard bands around each tone frequency. This further limits the number of tones which can be used and reduces the number of stations (addresses) which can be called.

A typical example of a single toneburst system is the 1750Hz, 600ms toneburst used to access amateur VHF and UHF repeaters in the UK and parts of Europe.

Sequential single tones. An obvious way of increasing the number of addresses which can be called is by sending tones sequentially. Each tone is sent for a short duration (typically 33 to 100ms) and the number of tones sent is predetermined (typically five tones). This sequential approach increases the number of addresses and hence stations that can be called to theoretically 100,000 for a 5-tone system.

In comparison the single toneburst systems can usually only support up to 40 or so tones within the audio passband of the radio. The CCIR, EEA and ZVEI 5 tone (see Table 1) selcall systems are the commonest examples of sequential tone systems.

Sequential dual tone systems. Dual tone multi-frequency (DTMF) tones are the signalling tones as used on the public telephone system. With DTMF two tone frequencies are transmitted simultaneously for typically 40ms, each tone pair representing a digit or a character in the extended DTMF tone group; 0 to 9, *, #, and A to D.

These tone pairs may be sent sequentially just as

Command | Tone sequence | Stations called
--- | --- | ---
Normal 5 tone selcall | F4 F3 F2 F1 F0 | 43891
5 tone selcall with repeated digit | F4 F3 F2 F1 F0 | 42227
10 address group call | F2 F1 F0 | 12340 To 12349
100 address group call | F2 F1 F0 | 29905 To 29995
All address call | F2 F1 F0 | 00000 To 99999
Transpond function | F4 F3 F2 F1 F0 | 100000

Fig. 1. Typical radio system audio spectrum showing the difference between audible in-band signalling (eg CCIR 5-tone selcall) and sub-audible out of band signalling (eg CTCSS).

Fig. 1. Typical radio system audio spectrum showing the difference between audible in-band signalling (eg CCIR 5-tone selcall) and sub-audible out of band signalling (eg CTCSS).

Fig. 2. Typical 5-tone selcall format indicating its flexibility and power.
In a telephone number to call a station and can provide a versatile approach to selcall. And of course the DTMF tone pairs may be used on the public telephone network during phone patches from the radio system.

**Sub-audible tone signalling.** An alternative to the in voice-band signalling uses signalling frequencies outside of the radio’s nominal 300-3500Hz audio passband. By using frequencies below 300Hz, a tone may be continuously transmitted allowing receiver audio output only when the sub-audible tone is present. This is in contrast to the in-band signalling, where the loudspeaker remains muted after a valid selcall tone or tone sequence allowing unwanted traffic to get through.

The sub-audible squeal system is known as continuous tone coded sub-audible squeal (CTCSS). Only receivers set to the same CTCSS tone frequency as that assigned to the transmitter will unmute on reception of a transmission. Other receivers set to different CTCSS tones will remain muted and the transmissions will not be heard. This privacy feature prompted Motorola – the inventors of the technique – to call it Private Line or PL.

Obviously if the user bypasses the CTCSS circuit then he will be able to hear all transmissions, even if they are not intended for the station. This by-pass feature allows monitoring for a free channel before making a transmission.

**Digital selective calling.** Although tone based selcall techniques were designed for analogue radio systems, digital selcall can be used on both digital and analogue systems. Digital techniques provide more addresses, higher transmission rates and error detection and correction protocols.

One such scheme is the digital selective calling (DSC), part of the Global Maritime Distress and Safety System (GMDSS). The DSC system is integral to the GMDSS concept (which became law by the 1st February 1999 for all ships at sea) as it provides the means of transmission and reception of distress messages between ships and coast radio stations. It also enables use as a conventional selcall system for normal voice traffic.

The DSC system is designed so that, by varying the data rate and modulation format, it can be configured for either HF or VHF marine communication systems.

**Selcall in detail.**

With the advent of multi-tone and digital technologies, single tone in-band selcall systems have almost disappeared except for the access of repeater systems, etc. The toneburst is sent at the beginning of the initial transmission and is produced by a high stability audio oscillator using a crystal or ceramic timedetector circuit block is a phase locked loop although vibrating reeds were used on early systems. Two tone sequential (two single tones sent one after each other) selcall systems are still used in some basic communication systems such as the Citizen Band radio system in the Scandinavian countries.

**Multiple sequential tone selcall.**

The sequential tone selcall systems and in particular the five tone variants are perhaps the most common selcall systems encountered in Private Mobile Radio (PMR). There are six major national and international tone-sets which are listed in Table 1.

The selcall sequence usually consists of a sequence of five single tones each tone representing a specific digit of the called station’s Selcall address or identity. In addition to the 0 to 9 tones there are additional tones:

- **Repeat tone** – The repeat tone is provided to

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
</tr>
<tr>
<td><strong>Tone Duration (ms)</strong></td>
</tr>
<tr>
<td><strong>Pause Duration (ms)</strong></td>
</tr>
<tr>
<td><strong>Code 0 (Hz)</strong></td>
</tr>
<tr>
<td><strong>Code 1</strong></td>
</tr>
<tr>
<td><strong>Code 2</strong></td>
</tr>
<tr>
<td><strong>Code 3</strong></td>
</tr>
<tr>
<td><strong>Code 4</strong></td>
</tr>
<tr>
<td><strong>Code 5</strong></td>
</tr>
<tr>
<td><strong>Code 6</strong></td>
</tr>
<tr>
<td><strong>Code 7</strong></td>
</tr>
<tr>
<td><strong>Code 8</strong></td>
</tr>
<tr>
<td><strong>Code 9</strong></td>
</tr>
<tr>
<td><strong>Repeat</strong></td>
</tr>
<tr>
<td><strong>Alarm</strong></td>
</tr>
<tr>
<td><strong>Free tone</strong></td>
</tr>
</tbody>
</table>

Note: Alarm tone frequencies can vary between manufacturers. Those shown above are for the chips produced by Consumer Microcircuits Ltd.

The above abbreviations stand for the following national and international standards organisations:

- **EIA** – Electronic Engineering Association (UK).
- **EIA** – Electronic Industries Association (USA).
- **CCIR** – Comité Consultatif International Radio Communication
- **CCITT** – Comité Consultatif International Télégraphique et Téléphonique
- **ZVEI** – Zentralverband der Elektrotechnischen Industrie (Germany).
The FX805 is a versatile sub-audible signalling processor designed for use with both CTCSS (continuous tone coded squelch) and CDCS (continuous digitally coded squelch) systems. It provides the encoding and decoding for continuous tone coded sub-audible squelch (CTCSS) using both standard and custom tone sets. It covers digitally coded squelch (DCS/DPL). This device also requires microcomputer control.

**TABLE 2**

<table>
<thead>
<tr>
<th>EIA continuous tone coded sub-audible squelch tone set</th>
</tr>
</thead>
<tbody>
<tr>
<td>67.0-XY 97.4-ZB</td>
</tr>
<tr>
<td>69.3-WZ</td>
</tr>
<tr>
<td>71.9-XA103.5-1A</td>
</tr>
<tr>
<td>74.4-WA</td>
</tr>
<tr>
<td>77.0-XB 110.9-2Z</td>
</tr>
<tr>
<td>79.7-WB</td>
</tr>
<tr>
<td>82.5-YZ 118.8-2B</td>
</tr>
<tr>
<td>85.4-YA123.0-3Z</td>
</tr>
<tr>
<td>88.5-YB 127.3-3A</td>
</tr>
<tr>
<td>91.5-ZZ131.8-3B</td>
</tr>
<tr>
<td>94.8-ZA136.5-4Z</td>
</tr>
</tbody>
</table>

**TABLE 3**

<table>
<thead>
<tr>
<th>Dual Tone Multi-Frequency tone set</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Group Tones</td>
</tr>
<tr>
<td>H1</td>
</tr>
<tr>
<td>H2</td>
</tr>
<tr>
<td>H3</td>
</tr>
<tr>
<td>H4</td>
</tr>
<tr>
<td>Low group tones</td>
</tr>
<tr>
<td>L1</td>
</tr>
<tr>
<td>L2</td>
</tr>
<tr>
<td>L3</td>
</tr>
<tr>
<td>L4</td>
</tr>
</tbody>
</table>

**Fig. 3. A DTMF selcall sequence for address 3A48 (The sequence could be of any length dependent on selcall system.)**

- Tone 1: 697 Hz
- Tone 2: 1477 Hz
- Tone 3: 1633 Hz
- Tone 4: 2035 Hz

**Continuous tone coded sub-audible squelch**

CTCSS is frequently used in combination with other selective calling techniques to provide an additional safeguard to prevent the reception of unwanted signals.
of unwanted transmissions. It was originally developed as a means to minimise the effects of co-channel interference in systems utilising repeaters.

By requiring a radio to continuously transmit a sub-audible tone to gain access to the repeater, the accidental re-transmission of signals caused by weak mixing products of other transmissions (which will not normally have the correct CTCSS access tone present) is prevented.

The standard Electronic Industries Association (EIA) frequency codes, in hertz, with their vented.

The correct CTCSS access tone present) is pre-transmissions (which will not normally have

nals caused by weak mixing products of other

dispersers. The accidental re-transmission of sig-

mit a sub-audible tone to gain access to the

repeaters. The accidental re-transmission of sig-

nals caused by weak mixing products of other

transmissions (which will not normally have

the correct CTCSS access tone present) is pre-

vented. The standard Electronic Industries Association (EIA) frequency codes, in hertz, with their

shown in Table 2.

**DTMF touch-tone**

The DTMF touch-tone technique was developed by Bell Laboratories in the mid-1960s to replace the conventional pulse (rotary) dialling used on the public switched telephone network. The advantages of DTMF have lead to worldwide adoption. DTMF decoders in single chip format decode the 16 possible DTMF tone pairs shown in Table 3.

Often the 2 of 8 tone system reduces to a 2 of 7, as signals in the 1633 Hz column are not used for conventional signalling on the public telephone network. However they can, and are, often used in radio selcall systems where DTMF tones are used for signalling. The DTMF tones were selected to avoid problems that can occur on telephony channels, for example frequencies used for each tone pair are chosen to avoid false triggering by voice signals (known as falsing).

The DTMF signalling format on the public telephone system is a 40ms tone duration and a 40ms inter-digit time. It has been found that radio systems function better with at least a 50ms tone duration and a corresponding 50ms inter-digit time (tone duration and inter-digit times of 70ms are common). DTMF has been successfully used on FM radio systems but, like many other tone based selcall systems, it is unusable on single sideband radio. This is because the necessary carrier regeneration at the receiver can cause unwanted phase and

**Silicon Systems DTMF**

Silicon Systems range of low-cost DTMF receivers (decoders) detect and decode DTMF tones. The introduction of these single chips has considerably simplified the design of DTMF selcall and signalling systems.

Until the introduction of these devices it was common to see complete 12 tone decoders constructed from seven 567 PLL ICs plus decoding logic. Each 567 required precise frequency adjustment and frequently the system's performance would degrade over time due to drift in each tone decoding section.

A simple DTMF selcall can be built around such a device as the 4514 4-to-16 decoder IC, a selcall system can be easily realised.

Mitel Semiconductors produce a similar range of DTMF encoders and decoders and their applications note Applications of the MT8870 Integrated DTMF Receiver gives examples of typical radio communication systems using DTMF signalling for Selcall and control.

**Silicon Systems (SSI) based DTMF Tone Decoder. The detected digit from the 4514 could drive a keyless lock and sequence detector IC such as the LS7225 to produce a low cost selcall system.**
The NE566 VCO and NE567 PLL tone decoder

The 566 is a general purpose voltage controlled oscillator which produces high stability square and triangular waves. The output frequency is a function of an external capacitor and resistor and, if desired, it may be linearly modulated by a control voltage. This device can be used as the basis of a tone generator in a simple tone calling system.

The output frequency of a 566 \( f_o \) is found from the equation:

\[
f_o = \frac{2.4 \left( V - V_i \right)}{R_1 C_1} \text{ Hz}
\]

where \( R_1 \) is between 2kΩ and 20kΩ, \( C_1 \) is in farads and \( V_i \) is the voltage between pins 5 and 1 of the IC. The 1nf capacitor between pins 5 and 6 is to prevent parasitic oscillations that may occur during VCO switching. One should note that the output waveform does not fall to zero volts and a suitable coupling capacitor will be necessary.

The NE567 is a phase-locked loop IC designed for general purpose tone and frequency decoding. The IC operates over a wide frequency range 0.1kHz to 1MHz and contains a logic compatible output which can sink up to 100mA. The bandwidth, centre frequency and output delay are determined using four external passive components.

The NE567 is a phase-locked loop IC designed for general purpose tone and frequency decoding. The IC operates over a wide frequency range 0.1kHz to 1MHz and contains a logic compatible output which can sink up to 100mA. The bandwidth, centre frequency and output delay are determined using four external passive components.

The detection frequency \( f_d \) is determined from the following:

\[
f_d = \frac{1}{R_3 C_3} \text{ Hz}
\]

where \( R_3 \) is between 2kΩ and 20kΩ and \( C_3 \) is in farads.

\( C_3 \) forms a simple lowpass post detection filter to eliminate spurious outputs due to out-of-band signals. The value of \( C_3 \) is not critical for most applications and, to eliminate the possibility of false triggering by spurious signals, the application sheet recommends that \( C_3 > 2C_2 \) where \( C_2 \) is the loop filter capacitance.

The detection bandwidth, \( BW \), is the frequency range centred about \( f_d \), for which a input signal (greater than the 20mV detection threshold voltage) will be detected by the IC. The detection bandwidth represented as a percentage of the centre frequency can be found from the approximation:

\[
BW = 10 \frac{V_i}{C_2 f_d} \%
\]

where \( V_i \) is the input voltage (volts rms) and \( C_2 \) is the loop filter capacitance in µF. The 567 can be used to detect single tones and with additional 567 devices and components dual tones (as in DTMF) and sequential tones. Details can be found in Exar Semiconductors' applications sheets.

**Aeronautical selcall systems**

The aeronautical radio service frequently uses selective calling techniques on HF radio to contact aircraft on transoceanic flights. An interesting aspect of the aeronautical selcall system is that only ground to air selective calling is available: the aircraft cannot selcall any other aircraft or ground station.

The purpose of the selcall system is to minimize the aircraft workload and remove the stress of continuously monitoring a noisy communication channel for calls.

The selcall signal sent by the ground station consists of two consecutive tone pulses of 1.0±0.25s duration, separated by an interval of 0.2±0.1s, each tone pulse consists of two simultaneously transmitted tones (similar to DTMF). The call should consist of one selcall tone sequence without repetition. A typical selcall address would be AG-CE which refers to Table 4, would consist of an initial burst of 312.6 and 582.1Hz tones followed by a second burst of 384.6 and 473.2Hz tones.

It is important to note that even though voice communications are predominantly in USB in the northern hemisphere, the selcall is always sent in a full carrier transmission, either full DSB or amplitude modulation equivalent (USB plus inserted carrier - H3E). This is because the selcall system cannot operate in the suppressed carrier single sideband mode. The necessary carrier insertion at the receiver can cause frequency translation errors, which would prevent satisfactory and reliable decoding of the selcall tones. As a result a dedicated AM detector is provided in the receiver solely for the demodulation and subsequent decoding of the transmitted selcall tones. This is unnecessary for aeronautical VHF radio which operates on AM.

With the tones above the number of available codes is 10,920. On detection of a valid selcall an audible warning (often a chime) and an indicator is triggered to warn the aircrew that they are being called by a ground station.

**Digital selective calling**

The maritime radio digital selective calling (DSC) system format is the same for both HF and VHF, only the modulation formats and signalling rates differ. A 7-bit binary code is used with three error correcting check bits, providing a total of 128 characters. The characters 00 to 99 are decimal numbers whereas 100 to 127 are reserved for specific service commands. These 10-bit character streams are formed into data fields where the selcall message is formatted. The user is able to select various formats for his selcall message:

1. Calls to all ships in a given area.
2. Distress call.
3. Calls to certain groups of ships (such as calls to one particular fleet).
4. All-ships call.
5. Calls to an individual ship or coast station.
6. Calls to a coast station providing automatic connection to the public telephone network.

The DSC system is very powerful and in the case of a distress call allows the inclusion of...
data fields describing the nature of the distress, the ship’s position (which can be provided automatically by the sat nav system) in addition to the time and ship identification. It is even possible to specify the preferred communication mode (radotelephone or radio teleprinter) for subsequent radio traffic.

The digital data stream is modulated using frequency shift keying. A frequency shift of ±85Hz is used on HF, ±85Hz for logic 0 and +85Hz for logic 1. For a SSB signal this equates to modulating tones of 1785Hz (logic 0) and 1615Hz (logic 1). The frequency shift keying is modified for the FM VHF service. The system modulates the carrier with tones of 2100Hz (logic 0) and 1300Hz (logic 1). HF signalling rate is 100 baud while on VHF 1200 baud is used (due to the wider channel bandwidths on VHF).

Maritime Mobile channel 70 (156.525MHz FM simplex) has been allocated exclusively for GMDSS. It is hoped that the introduction of DSC will increase the safety of all vessels and reduce the congestion of the International Calling and Distress channel 16 (156.800MHz FM simplex).

Selcall circuits
Single tone selcall decoders often consist of a PLL tone decoder such as the LM567 and driver circuitry to mute the audio and activate call indicators. (It should be noted that this device is particularly sensitive to input drive levels for reliable tone detection).

Multiple sequential tone selcall decoders and decoders tend to use custom asics which combine all the necessary functions onto a single device. For a SSB signal this equates to modulating tones of 1785Hz (logic 0) and 1615Hz (logic 1). The frequency shift keying is modified for the FM VHF service.

References
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Inductive and capacitive effects can be produced from a length of transmission line as opposed to the discrete (or lumped) elements used at lower frequencies.

Take, for example, a length of 50Ω microstrip transmission line on alumina operating at a frequency of 3000MHz. This requires a width to thickness ratio of unity, so that the effective dielectric constant is about 6.7 and the transmission line wavelength is about 4cm. A distance of 1cm, therefore represents a phase shift of 90°: sufficient to change an inductive reactance into a capacitive reactance.

In a conventional electronic circuit though, operating at, say, 300kHz, the same distance of 1cm might be typical of the size of a resistor or capacitor. But the phase change across this component would be just 0.0036° and would not affect its particular value of R, C or L. A lumped element, therefore, is one whose value does not change significantly with frequency. Generally, lumped elements measure less than about 1/20th of the transmission line wavelength. Conventional components start to show distributed effects above a few hundred MHz and they also become very lossy, so that different techniques must be used to produce the circuits. Fortunately, the higher the frequency, the smaller the value of inductance and capacitance necessary to produce a given effect and, at microwave frequencies, one is usually concerned with quantities of less than a few nH and less than a few pF.

Microwave hybrids and integrated circuits make use of printed features to implement reactive components. Mike Hosking* explains the design rules behind the patterns in the foil which replace components.

*Mike Hosking is a lecturer in telecommunications and microwaves at the University of Portsmouth.
Fabrication of the lumped elements is carried out using a photoetching process to define the circuits on low-loss substrates. The technology used is most important as, in order to be competitive with distributed circuits, high Q factors must be achieved. Inductors are formed from a length of narrow conductor track which, for inductances greater than about 1nH, can be extended into a planar spiral as in Fig. 1a.

Single-layer capacitances can be formed from the etched conductor ribbon by an interdigital arrangement shown in Fig. 1b, where use is made of the microwave fringing fields. This makes circuit processing simpler but, if a higher capacitance per unit area is required, then a three-layer metal-dielectric/metal sandwich can be used as in Fig. 1c for monolithic circuitry, or else an actual chip capacitor may be bonded into the circuit.

**Lumped inductors**

Any conductor possesses inductance, the value depending upon its geometry. For a strip whose thickness is very much smaller than its width, the inductance per unit length is a function of the length to width ratio, l/w. If the operating wavelength were, say 10cm, and the restriction that a component must be smaller than 1/20 of a wavelength were applied, then the permissible inductor length would be 5mm. For a width of 1.5mm, the l/w ratio is 20 and the inductance would be about 4nH, neglecting the conductor thickness. By decreasing the conductor width, the inductance may be increased or, alternatively, a shorter strip could be used. However, another factor must be taken into account before reducing the size too much and that is the inductor Q. This can be represented as the ratio of the reactance to the resistance and this resistance is the high-frequency value, which takes into account the skin effect.

The skin effect increases the dc resistance and is also a function of conductor geometry, the lowest resistance being obtained with a wide strip. In addition, the conductor thickness must be several times the skin depth. Theoretically, the Q factor of a lumped element inductor increases as the square root of frequency and this relationship is achieved in practice for a strip inductor at frequencies well into S-band (2000-4000MHz). Thereafter, the rate of increase of Q slows down as, for the same l/w ratio, the inductor becomes less "lumped".

Q factors greater than about 50 are required in order to achieve element losses of several tenths of a dB and, by taking care with substrate and conductor, such values can be obtained at 1000MHz, rising to a maximum of about 100 as the frequency increases. So far, attention has been confined to the strip inductor but, for higher inductance values, this can be formed as a circular or square spiral such as that shown in Fig 1a. Provided that the outside dimensions meet the size requirements, such an element will still appear as lumped. Its inductance, however, will be less than that of a strip of the same unwound length, due to the mutual proximity of the turns. Once again, the highest Q factor results from wide strips which, for a given inductor size, result in small, inter-turn spacings of the order of V/10 to V/20 of a millimetre. Typically, circuits at L band (1000-2000MHz) or S band (2000-4000MHz) frequencies require inductances of less than 5nH, which can be produced by less than two turns.

When printed dc bias lines are also included on the substrate, it is necessary to provide an rf choke (low-pass filter) to keep the rf out of the bias circuit, and inductances of 20-40nH are commonly used. A good example of spiral inductors on a GaAs monolithic circuit can be seen in the wireless LAN circuit in Fig. 5a of Part 1 (EW+WW April 1994). The closely-wound, larger spirals are about 0.4mm square comprising nine turns of high impedance line and would give an inductance of about 0.4nH.

Connection to the centre of multi-turn spirals can be made either by a conductor track deposited beneath the coil and insulated from it or by a bonded wire looped directly over the turns. In this way, some circuit tuning is possible by shorting out part of the turns or by bonding to different parts of the spiral.

**Capacitors**

Capacitors can be produced by the thin film, vacuum deposition technique in the two forms.
shown in Fig. 1b and 1c. The interdigital capacitor is economical to construct as it involves no more processing steps than are normally used with microwave ICs, that is, one plating and one etching operation. On the other hand, the parallel plate capacitor requires the deposition and etching of both a dielectric layer and another conductor.

The interdigital capacitance is produced by the rf fringe fields across the gap between fingers: to achieve usable values, the spacing must be small. Typically the finger gaps range from 0.05 to 0.02mm and, by varying the number of fingers, produce capacitance values up to 1pF.

Using such small gaps demands attention to the substrate surface finish, conductor thickness and the photo-etching process for consistent results. Values of capacitance less than 1pF generally find circuit application at frequencies of 8GHz and above in X band (8200-12,400MHz) and this type of structure can still remain a lumped element at these frequencies. Consequently, higher values of capacitance can be produced by using the parallel plate type of Fig. 1c; it does, however, involve additional deposition and etching. For compatibility with the vacuum deposition process, a commonly used dielectric material is silicon dioxide (SiO₂), although air-bridge designs can be used where the dielectric is air and the top conductor a self-supporting bridge. The capacitance of this type of structure is directly proportional to the area and, with a 1µm thick SiO₂ film, 0.022µF/in² can be obtained. Thus, an rf bypass capacitor of, say, 40pF, is only about 1mm square.

Much effort has been spent developing chip capacitors for microwave frequencies; single-layer ceramic capacitors can operate up to 10GHz, with values of capacitance between 1pF and 1000pF depending on the frequency. These components must achieve high Q-factors through low dielectric loss and low resistance contacts. However, the contacts themselves introduce self-inductance and, hence, a potential problem of self resonance. When selecting chip capacitors, such self resonance must be placed outside the operating frequency range and, indeed, manufacturers now characterise microwave capacitors with a complete set of s-parameter data.

Within the range of frequencies so far mentioned, the Q factor of capacitors tends to be higher than those for inductors. In the case of the parallel plate and ground plane aided structure, dielectric losses must be taken into account as well as those of the conductor. However, with good quality dielectrics, most loss can be attributed to the conductor material and the Q factor decreases with increasing frequency. At 1000MHz, Qs of several 100 or more may be achieved depending on technique, falling to 100 or less at 10,000MHz.

**Lumped assemblies**

The loss of lumped elements compares well with the measured loss in distributed microstrip circuits and this is important when designing such circuits as amplifiers. Higher power transistors, for example, have port impedances of a few ohms and, besides the inherent waste of power in the external circuit, the loss limits the degree of impedance matching, and hence power output, that can be achieved.

**Figure 2** shows a lumped element voltage controlled oscillator covering the 1-2GHz frequency band. The central transistor is bipolar and is tuned by a varactor diode, emitter coupled LC circuit. The inductance is formed by the single turn loop in the upper left hand corner and the varactor is mounted in the centre of the loop. The circuit includes two mos capacitors (black squares) and a larger ceramic chip capacitor. Various values of circular and rectangular spiral inductors may be seen, all printed on a ceramic substrate within a T0-8 encapsulation.

**Coplanar waveguide**

Although microstrip circuitry offers a high degree of component integration and is a relatively mature technology in terms of the availability and accuracy of design tools, it does have some restrictions. It is not truly uni-
planar, due to the ground plane being on the opposite side of the substrate to the circuitry and it is thus inconvenient for designing and fabricating shunt components. In addition, lumped elements such as the spiral inductors and interdigital capacitors described previously have parasitic capacitance due to the ground plane. This reduces the self-resonant frequency of these components and, hence, their useful operating range.

CPW, Fig. 3, overcomes these problems and also offers a higher level of integration (about 30%). Consequently, much microwave circuit design effort, particularly for the communications industry, is being concentrated on CPW. Circuits will operate well into the millimetre wave region above 30GHz and monolithic circuits on GaAs have been produced at 60GHz.

As Fig. 3 shows, both the circuit itself and the ground plane are on the same side of the substrate, thus no holes need be made for shunt components and parasitic affects are reduced. In fact, lumped elements are used up to 30GHz. The fields propagate in a mode pattern confined to the main conductor strip of width \( w \) and the two slots of width \( s \). The characteristic impedance is a function of the ratio:

\[
\frac{s}{s + 2w}
\]

A typical range of values is shown in Fig. 4 for the cases of a fused quartz substrate (\( \varepsilon_r = 4 \)) and a GaAs substrate (\( \varepsilon_r = 13 \)).

### Recommended Frequency Range (GHz) | TE_{02} Cutoff Frequency (GHz) | Inside dimensions (inches) | Characteristic Impedance (GHz)
--- | --- | --- | ---
1.12 - 1.7 | 0.908 | 6.500 - 3.250 | 60.500
2.60 - 3.95 | 2.078 | 2.840 x 1.340 | 1.372
5.85 - 8.20 | 4.301 | 1.680 x 0.622 | 0.900
8.20 - 12.4 | 6.557 | 2.000 x 0.800 | 0.900
12.4 - 18.0 | 9.486 | 1.000 x 0.400 | 0.622
18.0 - 26.5 | 14.047 | 0.240 x 0.311 | 0.240
26.5 - 40.0 | 21.081 | 0.120 x 1.40 | 0.280
40 - 60 | 31.357 | 0.080 x 0.094 | 0.188
50 - 75 | 39.863 | 0.040 x 0.074 | 0.148
75 - 110 | 59.010 | 0.020 x 0.050 | 0.100
110 - 170 | 90.854 | 0.010 x 0.0325 | 0.065
140 - 220 | 115.75 | 0.005 x 0.0255 | 0.051

Table 1. Rectangular Waveguide Data

For any low-loss transmission line, the characteristic impedance \( Z_0 \) can be expressed as:

\[
Z_0 = \frac{L}{C}
\]

where \( L \) and \( C \) are the inductance and capacitance per unit length, respectively. It is relatively simple to evaluate \( L \) and \( C \) for coaxial line to yield:

\[
Z_0 = \left( \frac{60}{\varepsilon_r} \ln \frac{b}{a} \right)
\]

This is the equation plotted in Fig. 4.

### Waveguide

Although all transmission lines are waveguides, the term has come to apply to the dielectric-filled conducting tube the dielectric usually being air. Nowadays, waveguide is mainly used when high powers are involved - for instance - to guide the signal from transmitter to antenna and in certain complex antenna feeds where minimum loss is paramount. However, the size and weight of waveguide, together with a relatively narrow frequency range for a particular size, prohibits its use in integrated circuits.

For a given size of waveguide (\( a \times h \)) there is a lower frequency limit below which no microwave field can propagate; this is termed the cut-off frequency. As the frequency is raised, the first sustainable mode will form, termed the dominant mode and, with further increases in frequency, other higher order modes will appear. Thus, waveguide (and all transmission lines) behave as high-pass filters but are almost invariably restricted to operation in the dominant mode.

To operate at a higher frequency, the wave-
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guide cross sectional dimensions must be progressively reduced so as to prevent the formation of higher order modes. This leads to a range of standard waveguide sizes, some of which are shown in Table 1 for rectangular guide. With few exceptions, the aspect ratio is fixed at 2:1, this being a compromise between power handling, losses and over-moding. The internal dimensions of waveguide operating above 100GHz become quite small, so that the difficulty of creating circuit components within these dimensions increases.

The longest wavelength which can propagate down rectangular waveguide (that corresponding to the dominant mode) is equal to twice the width of the guide, $2a$. In practice, the centre frequency is made equal to about 1.5 times the cut-off frequency and actual operation is restricted to within about ±20% of this. For circular waveguide, the cut-off wavelength of the dominant mode is 3.42$r$.

The reason for restricting waveguide transmission to microwave frequencies becomes apparent from Table 1: to cover the FM broadcast band from 88MHz would require a rectangular waveguide of a size which could garage two family cars side by side.

Coaxial line

Unlike waveguide, coaxial line has no cut-off frequency: a given size will propagate signals down to zero frequency and up to infinity. The principle mode of transmission in coaxial line is termed transverse electromagnetic (TEM) meaning that all components of electric and magnetic field are at right angles to the direction of propagation. This mode requires a geometry of at least two conductors and, hence, cannot exist in waveguide. Higher order modes are possible but are almost always undesirable and start to occur when their wavelength approaches the mean circumference of the line. Thus, in practice, there is a restriction on the upper frequency of coax, usually around 40GHz.

Coaxial cable is normally filled with a dielectric material, usually polyethylene or PTFE and so the velocity of propagation is slowed from that in free space by an amount dependant upon the dielectric constant (relative permittivity) of the material, $\varepsilon_r$. For the TEM mode, the phase and group velocities are equal, so that the velocity in the line is simply $v/c = \varepsilon_r/v_e$. Typical values for $\varepsilon_r$ at 10GHz (there is a slight frequency dependence) are 2.25 for polyethylene and 2.08 for PTFE.

The value of 50Ω characteristic impedance has become the most widely used standard for coaxial connectors and instrumentation input/output ports. 75Ω is largely used for signal connections to dipole-type antennas since the basic $\lambda/2$ dipole has an input impedance of approximately 73Ω. Characteristic impedance and several other parameters of coaxial line are functions of the ratio of outer and inner diameters, as shown in Fig. 6 for the case of PTFE dielectric. Coaxial impedances found in practice range typically from 20Ω to 150Ω, with standard 50Ω line having a diameter ratio $b/a = 3.3$ for this dielectric.

It is interesting to note that, for characteristics such as attenuation, voltage breakdown and power handling, there are optimum, but different, ratios of $b/a$.

Lowest conductor loss occurs for a value of 3.6, maximum voltage capability for 2.7 and maximum power handling for 1.65 corresponding to impedances of 53.3Ω, 41.3Ω and 20.8Ω respectively.

![Fig. 5](image_url)

Fig. 5. Continuity of the ground planes must be maintained in coplanar waveguide and so the technique of forming air bridges over the conductor tracks is used. Consequently, a 3D CAE analysis must be developed for accurate calculation and simulation of the fields.

![Fig. 6](image_url)

Fig. 6. There is an optimum ratio of outer to inner radii for a coaxial line depending on the transmission characteristics required. These are shown here for the case of an air-filled line where it can be seen that the usual 50Ω impedance gives a compromise between these optima.
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Racat/Dana 50-462 Digital Multimeter.
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Racat/Dana 3712 TX Drive Units 1-30MC/s - £500-£750.
Mike Button looks at the more practical side of I²C design – including a worked example of an I²C frequency synthesiser – having covered I²C theory in the January issue.

Busman's guide to I²C

Designed by Philips, the inter-integrated circuit bus allows bi-directional data communication over two wires at up to 100kbps. Abbreviated to I²C, the bus has a defined protocol allowing transfer between any number of master and slave devices – in theory. There is automatic arbitration for multi-masters and devices can be added or removed without transgressing the bus protocol.

A list of the more popular master and slave bus ICs is presented in Table 1.

Writing I²C drivers

In most control applications, a single microcontroller performs all functions. As a result, the I²C bus multi-master feature is not essential. Not all proprietary slave devices need clock timing and synchronisation control so these are not always needed either.

Provided that the microcontroller has suitable spare I/O pins and there is room in its ROM, a simple software driver for an I²C bus can be added to enhance existing systems. Note that the I²C bus specification states that devices can be added or removed at any time and that the bus should function correctly even if the power supply to a particular device or board is removed.

In the event of a power failure, the open-collector output on the bus lead is needed to prevent the wire being pulled to ground via the inherent parasitic diode at the V_{cc} connection. This requirement is automatically fulfilled with the specified open collector wired-AND logic function.

If all devices connected to the bus are supplied from a single power source – as is normally the case – a further relaxation in the bus specification is allowable. Both SDA and SCL can be connected directly to the quasi bi-directional ports of an 8048 or 8051 type microcontroller.

Using microcontrollers with active pull-up ports whose direction is software defined will need two pins per I²C bus lead. One forms an output connected to the bus via an open-collector device, the other an input connected...
### Table 1. A multitude of IC controllable devices is now available. In the slave address bit descriptions, U represents a user-defined bit which is normally a hardware strap. Letter A signifies a software-defined or pre-allocated bit. Symbols in the read/write column, i.e. bit 0 of the slave address, are ‘U’ for read only, ‘Y’ for write only and ‘A’ for read or write. Slave devices are listed below, microcontrollers bottom right.

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Slave Address</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory</td>
<td>CAT24C02</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A CATALYST</td>
</tr>
<tr>
<td></td>
<td>CAT24C04</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A CATALYST</td>
</tr>
<tr>
<td></td>
<td>NM24C01</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Nat Semi</td>
</tr>
<tr>
<td></td>
<td>NM24C02</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Nat Semi</td>
</tr>
<tr>
<td></td>
<td>NM24C04</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Nat Semi</td>
</tr>
<tr>
<td></td>
<td>NM24C08</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Nat Semi</td>
</tr>
<tr>
<td></td>
<td>PCF8591</td>
<td>EEPROM 126 x 70</td>
<td>1010 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8592</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8594</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8598</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>X2C420</td>
<td>EEPROM 126 x 70</td>
<td>1010 UUU A Xicor</td>
</tr>
<tr>
<td></td>
<td>X2C42C</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Xicor</td>
</tr>
<tr>
<td></td>
<td>X2C420</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Xicor</td>
</tr>
<tr>
<td></td>
<td>X2C42C</td>
<td>EEPROM 256 x 8</td>
<td>1010 UUU A Xicor</td>
</tr>
<tr>
<td></td>
<td>PCF8570</td>
<td>RAM 256 x 8</td>
<td>1010 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8571</td>
<td>RAM 128 x 8</td>
<td>1010 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8583</td>
<td>RAM 256 x 8</td>
<td>1010 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>I/O</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PCF8565</td>
<td>LCD Driver, 96 segments</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8568</td>
<td>LCD Row Driver</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8569</td>
<td>LCD Column Driver</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8574</td>
<td>8 bit I/O</td>
<td>01000 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8574A</td>
<td>8 bit I/O</td>
<td>01111 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8576</td>
<td>LCD Driver 160 segments</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8577</td>
<td>LCD Driver, 64 segments</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8577A</td>
<td>LCD Driver, 64 segments</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8579</td>
<td>LCD Row/Column Matrix Driver</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8579A</td>
<td>LCD Row/Column Matrix Driver</td>
<td>01111 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAIA064</td>
<td>LED driver 4 digits</td>
<td>01111 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>SAIA1004</td>
<td>LED high current driver</td>
<td>01000 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>Analogue</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PCF8591</td>
<td>4 channel 8 bit ADC with 8 bit DAC</td>
<td>10101 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4444</td>
<td>Octal 6 bit DAC</td>
<td>10100 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4442</td>
<td>Quad 6 bit DAC</td>
<td>10100 UUU 0 Philips</td>
</tr>
<tr>
<td>Audio</td>
<td>PCD2311</td>
<td>Tone Generator, DTMF - Modern - Music</td>
<td>01001 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCD3312</td>
<td>Tone Generator, DTMF - Modern - Music</td>
<td>01001 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>PCF8200</td>
<td>Voice Synthesizer</td>
<td>01000 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TEA6300</td>
<td>Sound Fader Control</td>
<td>10000 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TEA6310</td>
<td>Sound Fader Control</td>
<td>10000 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4201</td>
<td>HiFi Stereo Audio Processor</td>
<td>10000 U 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4425</td>
<td>Audio Processor with LS channel</td>
<td>10000 U 0 Philips</td>
</tr>
<tr>
<td>Radio</td>
<td>TGA5510</td>
<td>1.3 GHz Frequency Synthesizer</td>
<td>11000 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>TGA5611</td>
<td>PLL Frequency synthesizer for TV</td>
<td>11000 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>TGA5657</td>
<td>PLL Frequency synthesizer for Radio</td>
<td>11000 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>UMA1010</td>
<td>PLL Frequency synthesizer Low Power</td>
<td>11000 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>UMA1009</td>
<td>PLL Frequency synthesizer</td>
<td>11000 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>TEA6100</td>
<td>FM/FM Tuning interface</td>
<td>11000 UUU A Philips</td>
</tr>
<tr>
<td>Television</td>
<td>SAA1136</td>
<td>PCM Audio input device</td>
<td>00111100 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAA2434</td>
<td>Enhanced Teletext Circuit</td>
<td>001001 A 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAA7191</td>
<td>S-VHS digital multistandard decoder</td>
<td>11000 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAA7192</td>
<td>Digital colour space converter</td>
<td>01000 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>SAA7195</td>
<td>Digital Encoder</td>
<td>11000 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAA9020</td>
<td>Field Memory Controller</td>
<td>01001 UUU A Philips</td>
</tr>
<tr>
<td></td>
<td>SAA9050/1</td>
<td>Digital Multi-Standard TV decoder</td>
<td>10100 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAA9068</td>
<td>Picture in picture controller</td>
<td>01010 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAA3035</td>
<td>CPU interface for tuning &amp; control</td>
<td>11100 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>SAF1135</td>
<td>Data Line Decoder, (Teletext)</td>
<td>01000 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4670</td>
<td>Picture in Picture Improvement Cct.</td>
<td>10000000 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4680</td>
<td>Video Processor</td>
<td>10100 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4440</td>
<td>ATV Receiver Switch</td>
<td>10000 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4442</td>
<td>Colour Decoder Switch</td>
<td>10000 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4443A</td>
<td>YUV/RGB interface</td>
<td>11100 UUU 0 Philips</td>
</tr>
<tr>
<td></td>
<td>TDA4461</td>
<td>PAL/NTSC colour decoder</td>
<td>10000 UUU 0 Philips</td>
</tr>
<tr>
<td>Bus Controllers</td>
<td>PC8594</td>
<td>Bus Controller</td>
<td>N/A Philips</td>
</tr>
</tbody>
</table>

Flow of the functions needed for a simple I2C bus software driver is shown in Fig. 1. Suitable for any microcontroller, this routine provides for minimum SCL high and low times. It also takes advantage of the fact that the SCL clock high and low periods can be any ratio.

Master transmitter/receiver facilities only are provided for by the driver. It assumes that no other master will attempt to access the bus and that any slave will not attempt to perform SCL clock synchronisation.

Subroutines for the start, transmit, receive and stop conditions are shown. These need a control software routine designed to access the particular slave device being used, examples of which are given later.

The start routine assumes that the bus is in an idle state as left by the stop routine, i.e. SDA and SCL high, or that SCL is low as left by the transmit or receive routines. On initialisation, the control routine should set SCL and SDA high. Both transmit and receive routines count and control SCL timing. They assume that the software instruction set can shift, i.e. rotate, the contents of an eight bit data register for parallel-to-serial conversion.

To transfer data, the required slave device must first be accessed by sending its address. This is achieved by sending a start condition followed by a transmit with the data register loaded with the required address. For a master transmit function, the data register must be loaded with the slave address bit 0 at logic zero, signalling write. The master receiver function requires that the data register must be loaded with the slave address bit 0 at logic one, representing a read.

In the transmit routine, the data register is preloaded from the control software. All eight bits are shifted through bit 7. The SDA lead is directly to the bus wire.

Base code of some of the more popular devices:

<table>
<thead>
<tr>
<th>Device</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3315</td>
<td>68000</td>
<td>8048 wide vol range for telephony functions</td>
</tr>
<tr>
<td>68000</td>
<td>68000</td>
<td>68000 CPU with MMU/UART/DMA/timer</td>
</tr>
<tr>
<td>830525</td>
<td>8051</td>
<td>micro-controller with 512 bytes RAM</td>
</tr>
<tr>
<td>830552</td>
<td>8051</td>
<td>micro-controller with 256 bytes RAM</td>
</tr>
<tr>
<td>830552</td>
<td>8051</td>
<td>8 channel 10 bit ADC, 2 8 bit PWM</td>
</tr>
<tr>
<td>83C652</td>
<td>8051</td>
<td>micro-controller with 256 bytes RAM</td>
</tr>
<tr>
<td>84C00</td>
<td>8048</td>
<td>256 byte RAM, Bond out version.</td>
</tr>
</tbody>
</table>
given the state of bit 7 prior to raising the SCL lead thus the transmitting contents of the data register to the bus in a serial form.

The routine assumes that the control routine will monitor the number of bytes to be sent. If a NACK is received from the slave or after all the bytes are transmitted to the slave, a stop or repeated start routine must be executed.

To receive a byte the slave should first be addressed by using the transmit routine. Each time the SCL lead is set high, i.e. that the start, receive routine. Data is then shifted left until all eight bits are loaded.

Receiving assumes that the control routine indicates whether to send an ACK or a NACK after receipt of each byte. After sending a NACK signal, the control routine must then execute either a repeated start or stop to terminate the receive procedure. The stop routine assumes that SCL is low, i.e. that the start, transmit or receive routines have been previously executed.

Note that these routines produce a relaxed form of the bus protocol. Checks for arbitration and clock synchronisation are not performed. Under the I2C patent, buying Philips I2C components conveys a license to use the software drivers are more involved.

For hardware terms, I2C bus is relatively simple and clock synchronisation are not performed. Under the I2C patent, buying Philips I2C components conveys a license to use the I2C frequency synthesiser.

There is also a dedicated I2C bus interface for use with almost any 8 or 16 bit microprocessor or microcontroller, the PCD8584. It provides for multi-master, multi-slave configurations and can be accessed as a DMA (direct memory access) port.

I2C frequency synthesiser

One of several I2C-controlled frequency synthesizers, namely the TSA5510, was mentioned in the article Closing the loop, EW+WW June '93. This device operates at frequencies to 1.3GHz.

In the design shown in Fig. 2, a 74HCT4046 provides the voltage-controlled oscillator and a TSA6057 radio tuning frequency synthesizer acts as the I2C bus device to keep cost down and simplify the circuit.

Control of the TSA6057 is achieved by sending instructions to five write-only control registers, Table 2. A low cost 80552 Cameo development system connected to a PC compatible produced the I2C bus signals.

Made by TDR, the Cameo board is a low-cost produced the I2C bus signals. It operates at megahertz frequencies, the signals needed to control it can be conveniently conveyed via the economical I2C bus.

Fig. 2. Although this frequency synthesiser operates at megahertz frequencies, the signals needed to control it can be conveniently conveyed via the economical I2C bus.
cost system for developing and testing 8051 source code. Its monitor program has an I²C driver built in. The system is supplied with an applications program which uses this driver to provide a simple RS232-to-I²C converter.

Commands sent from a communications program called Procomm are loaded via a PC RS232 port to the Cameo board. They then pass via Cameo's I²C bus program to the TSA6057. Using these commands, oscillation frequency of the VCO is variable from 7 to 22MHz.

Setting of a particular frequency is easy. First, the Cameo I²C-to-RS232 converter is loaded. An interrogator function then checks for slave devices by sending out addresses and looking for a response. Finally, the slave address is set.

To set a frequency of 8.192MHz for example, i.e. a 1kHz reference frequency multiplied by 8192, the internal registers need to be set accordingly:

<table>
<thead>
<tr>
<th>Subaddress</th>
<th>0016</th>
<th>Data byte 0</th>
<th>0016</th>
<th>Data byte 1</th>
<th>4016</th>
<th>Data byte 2</th>
<th>1016</th>
<th>Data byte 3</th>
<th>0016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>00 00 00</td>
<td></td>
<td>00 11 00</td>
<td></td>
<td>00 11 11</td>
<td></td>
<td>00 11 11</td>
<td></td>
</tr>
</tbody>
</table>

Using the converter command T0000401000, data transmitted to the TSA6057 prototype resulted in a frequency reading of around 8.192MHz. Other code combinations were tried and the frequency output varied proportionately to the sent code.

I noticed considerable frequency jitter which was due to the loop coming in and out of lock. As I took no particular care with board layout and capacitor choice this jitter was not surprising. The prototype circuit did prove, however, that a synthesizer using the TSA6057 was a practicable proposition provided care was taken in the layout and choice of components.

Data and time via I²C

Where accurate time of day and calendar data are needed the PCF8583 provides a low power source. The eight-pin device has a four year calendar, giving time and date to a resolution of 10bits, and a 256byte ram. An alarm function can be set to any time up to four years away. There is also a timer which can be set to count an elapsed time up to 99 in seconds, minutes, hours or days. Table 3.

An open-drain interrupt pin can be configured to pull low when a clock or timer alarm is activated and there is provision for allowing two devices to be connected to the bus. Clock, calendar, alarm and timing functions use the

<table>
<thead>
<tr>
<th>Slave Address register</th>
<th>7 6 5 4 3 2 1 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Register 0</td>
<td>S6 S5 S4 S3 S2 S1 S0 CP</td>
</tr>
<tr>
<td>Register 1</td>
<td>7 6 5 4 3 2 1 0</td>
</tr>
<tr>
<td>Register 2</td>
<td>S14 S13 S12 S11 S10 S09 S08 S07</td>
</tr>
<tr>
<td>Register 3</td>
<td>7 6 5 4 3 2 1 0</td>
</tr>
<tr>
<td>Test bits, always &quot;000&quot;</td>
<td>------</td>
</tr>
</tbody>
</table>

The first 16 bytes of the internal ram, the remaining 240 bytes are available to the user. While in circuit mode, maximum current consumption of the device is 50µA. Current taken during access by the I²C bus is 200µA maximum. Timing can be derived from either a 32.768kHz crystal or a mains-derived 50Hz signal.

One application, which is not immediately obvious, is the provision of a 'wake-up' facility on systems where current consumption is important. For example, during the period between taking samples, automatic logging equipment normally performs no function. During these periods, power to all system components except the 8583 can be turned off to conserve the batteries.

By using the alarm function and interrupt output of the 8583 it is possible to provide a hardware power switch on to devices previously switched off.

Power down and power up facilities may be achieved as follows. Prior to switch off, write the relevant status data into the 8583 ram, i.e. what the processor should do next after waking up. Set the alarm or timer to activate at the required time in the future. Go to the switched off condition by programming the processor to remove the power-on latch.

On receipt of the wake up signal, the 8583 interrupt goes low, turning on the power. Power is latched on when the processor powers up. Next, status and any other relevant information is read from the 8583 ram. At the end of operating period, the system is switched off as explained above.

Driving leds

Primarily the SAA1064 led driver is intended for controlling four seven segment leds. However it has the capability to drive 16 wires with maximum current of 21mA at up to 15V. The only restriction is the maximum chip dissipation of 1W.

The device makes an excellent relay or lamp driver. Functions of the eight internal registers are given in Table 4. Up to four devices may be connected to a single bus.

Assembled as constant current drivers, the 16 outputs can be controlled to sink current up to 21mA. Output current can be set in steps of 3mA from 0 to 21mA. Provided that the maximum chip dissipation is not exceeded, each output can drive a led or incandescent lamp without needing a series resistor.

Four different slave addresses can be chosen.

Provision is made to multiplex the 16 outputs to allow for 32 lamps or segments. In this mode average current per output is 50% of the set current. Both multiplex outputs are active high and can drive a minimum of 30mA.

Make I²C go further

Open-collector And connections are used to implement the I²C bus. These allow flexibility but at the expense of limiting interconnecting bus-line lengths. This is why it is called the inter-integrated-circuit bus.

All devices on the bus are guaranteed to work only if the rise time and fall times of the electrical signal on the SDA and SCL lines are below a certain minimum. Open-collector drivers need a resistor to pull them to VEE.

Total capacitance presented to this bus pull-up restricts rise and fall times.

Total bus capacitance is the sum of input capacitances of all connected devices plus capacitance of the bus wire. As the distance between devices increases, capacitance of the bus wire also increases. Signal rise time depends, therefore, on the number of devices present and the capacitance of the bus wire.

Under normal circumstances bus capacitance limits the distance over which satisfactory data transfer can be performed.

Transmission line techniques can be used to assure that bus rise and fall times meet the I²C bus specification over any length of line. Propagation velocity of the line then becomes the limiting factor, restricting maximum bit rate.

I²C Specification summary

<table>
<thead>
<tr>
<th>Max. bus frequency</th>
<th>100kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. SCL high time</td>
<td>4.7µs</td>
</tr>
<tr>
<td>Min. SCL low time</td>
<td>4µs</td>
</tr>
<tr>
<td>Max. input rise time</td>
<td>1µs</td>
</tr>
</tbody>
</table>
256 byte non-volatile RAM.

Table 3. In addition to real-time clock information, this I2C-controlled IC has a 256 byte non-volatile RAM.

Clock Function

<table>
<thead>
<tr>
<th>Dev.</th>
<th>Bit Number</th>
<th>Addr</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>7654</td>
<td>3210</td>
<td>Control/Status</td>
</tr>
<tr>
<td>01</td>
<td>7654</td>
<td>3210</td>
<td>Function</td>
</tr>
<tr>
<td>02</td>
<td>7654</td>
<td>3210</td>
<td>Data &amp; Month Mask</td>
</tr>
<tr>
<td>03</td>
<td>7654</td>
<td>3210</td>
<td>Hold Count</td>
</tr>
<tr>
<td>04</td>
<td>7654</td>
<td>3210</td>
<td>Start Condition</td>
</tr>
<tr>
<td>05</td>
<td>7654</td>
<td>3210</td>
<td>Stop Count</td>
</tr>
<tr>
<td>06</td>
<td>7654</td>
<td>3210</td>
<td>Tenths</td>
</tr>
<tr>
<td>07</td>
<td>7654</td>
<td>3210</td>
<td>Units</td>
</tr>
</tbody>
</table>

Alarm Function

<table>
<thead>
<tr>
<th>Dev.</th>
<th>Bit Number</th>
<th>Addr</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>08</td>
<td>7654</td>
<td>3210</td>
<td>Alarm Control</td>
</tr>
<tr>
<td>09</td>
<td>7654</td>
<td>3210</td>
<td>Alarm Function</td>
</tr>
<tr>
<td>0A</td>
<td>7654</td>
<td>3210</td>
<td>Seconds</td>
</tr>
<tr>
<td>0B</td>
<td>7654</td>
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<td>Minutes</td>
</tr>
<tr>
<td>0C</td>
<td>7654</td>
<td>3210</td>
<td>Hours</td>
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<tr>
<td>0D</td>
<td>7654</td>
<td>3210</td>
<td>Days/Year</td>
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<tr>
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<td>7654</td>
<td>3210</td>
<td>Months</td>
</tr>
<tr>
<td>0F</td>
<td>7654</td>
<td>3210</td>
<td>Timer</td>
</tr>
</tbody>
</table>

Max. input fall time

300ns

Time SDA must be stable prior to rising edge on SCL

250ns

Max. input voltage

1.5V

Min. input high voltage

3.0V

Max. output low voltage

400mV

Typ. high leakage current

10μA

Max. input capacitance per device wire

10pF

Max. bus capacitance

400pF

A start condition is defined as a falling edge on the SDA line while SCL is high. Similarly, a rising edge on SDA when SCL is high defines the stop condition.

Bus capacitance limitations

In practical systems, bus capacitance is either known or can be estimated. A good approximation is to assume each device on a single circuit board presents 20pF. This comprises 10pF input capacitance and 10pF track capacitance. Capacitance per metre of interconnect needs to be obtained from the manufacturer’s data. Typically, 75Ω television antenna cable is 70pF/m.

A good approximation for bus voltage rise time is obtainable by multiplying the pull-up resistor value by the bus capacitor. This value should not exceed 1μs. Although not strictly correct, the CR time constant gives a near enough approximation for most applications.

The minimum value of the pull-up resistor is restricted by pull-down current which should not exceed 3mA for unbuffered devices.

Account of the 10pA leakage current from each device on the bus needs to be taken when calculating the pull-up resistor.

It is sometimes necessary to protect devices from bus voltage transients by inserting a resistor in series with the device pin. This further complicates the calculations. Further information on this subject is available in Philips' data sheets.

Propagation velocity restrictions

Due to the I2C bus open-collector And function, all master transmitting devices monitor their own signals to detect for the presence of other masters. A received logic low when transmitting a high indicates the presence of another device.

In most systems, the delay caused by the time taken for an electrical signal to pass down a wire can be ignored. When attempting to use the I2C bus over long distances, transmission delay time of the bus wires limits the data rate.

When calculating the maximum line length for a given data rate, response and hold times of all devices have to be taken into account, in addition to propagation delay.

The acknowledge signal is a typical example. A low acknowledge signal on SDA from the remote end must be received 250ns prior to the local end SCL rising edge. At 100kbps, the local SCL clock is low for

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Fig. 3. Adding current buffers at each end of the I'C link extends communication distance considerably. It also allows cheaper cabling.

Fig. 4. Normally, an I'C link relies on a common return path. Adding high-speed opto couplers not only provides galvanic isolation but can also extend communication distance or increase the permissible number of devices connected.

Fig. 5. Transmission-line techniques add a little complexity to I'C but in return they increase communication distance to infinity - in theory.

4.7µs. This leaves 4.45µs, from the falling edge of SCL to detect the state of the distant SDA signal.

Where propagation velocity is light speed, maximum bus length is 4.45µs x 300/2 = 667m. This calculation ignores device response time and the velocity factor of the cable. It is unlikely that a line length of 500m can be exceeded for a rate of 100kbaud.

Dedicated I'C bus extender

Within the 82B715 bipolar integrated circuit are two identical buffer circuits. These enable the I'C bus to be extended over longer distances without degrading performance.

Each buffer preserves the bi-directional open-collector characteristic of the I'C SDA and SCL lines. The circuit is supplied in plastic eight pin DIL or small outline packaging.

Practical communication distances are limited to a few metres by the I'C bus capacitance limit of 400pF. Using one 82B715 pair at each end of longer cables reduces effective loading capacitance on the bus. This allows communication via low cost general-purpose wiring.

Each of the buffers has a current gain of ten. Impedance seen at an input is therefore ten times the output (line) impedance.

Figure 3 shows a typical minimum system configuration.

Galvanic isolation

The I'C bus assumes that there is a common return between all connected devices. It is sometimes necessary to run two or more systems each with their own independent power supply.

Under these circumstances, a direct connection between the different systems is undesirable, impossible or even dangerous.

High speed opto-couplers now available make it possible to provide a galvanic barrier between I'C bus systems, Fig. 4. Two such circuits are needed, one each for the SCL and SDA lines. Note that bus capacitance on one side of the isolator does not reflect to the other side.

By using two or more sets of isolators, one
at each end of the bus, it is possible to extend the distance between systems and/or increase the number of connected devices beyond the 400pF limit.

**I²C via transmission-line**

An extension of the previous isolation principle is to separate send and receive signals for each of the SCL and SDA signals and send them down independent transmission lines, Fig 5. With this arrangement the distance between ends can approach infinity. The only limitation is the velocity of propagation of the transmission lines which restricts the maximum baud rate. The main disadvantage of this system is the cost of two transmission lines per I²C bus lead.

**Summary**

The I²C' bus was created to provide a low cost, yet adaptable intercommunication medium for use in the television and audio market. Although it was originally intended to be an inter-integrated-circuit bus for devices on the same PCB, the range of about 4m made it a very useful media for data exchange between units on the same shelf. Using 82B715 buffer ICs can extend the range to several tens of meters making the bus useful for control and monitoring functions in buildings.

**Further reading**

The following Philips component application notes and data handbooks provide definitive information on the I²C bus specification and available devices:

- I²C bus specification, 9398-336-70011.
- I²C bus compatible ICs, book 4, parts 12a & 12b 1989.
- I²C peripherals for microcontrollers, 1992.
- Single chip 8-bit microcontrollers, PC883552/562 handbook.
- Interfacing PCD8584 I²C, application note, Feb. 90.
- Applications report PCT8584, I²C-Bus Controller, Mar 93, 9390-316-20112.

**Other publications of interest:**

- Embedded Applications Journal No 1, Intel.
- EPROMS, EPOTs, NOVRAMs Data Book, Xicor.
- Cameo Applications, TDR Ltd.
- I²C Bus Specification, Philips
- 82B715 Data Sheet, Philips

**I²C driver on disk**

A 3 assembly-language listing for a simple I²C driver is available on disk. This listing is written specifically for the PCE83C552 controller in 8051 code. It can be obtained by sending £10 all inclusive to Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS. Please mark your envelope I²C software.

**I²C bus devices and data sheets can be obtained from Philips and their distributors.**

I have found Gothic Crellon at Wokingham, Tel. 0734 788876 and Quarndon at Derby Tel. 0332 332651 very helpful.

Help and further information on bus devices and the Cameo board may be obtained from me at TDR Ltd. Tel 0666 377464. TDR can obtain specific devices for experimentation.

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**CIRCLE NO. 116 ON REPLY CARD**

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Arnold Sugden—pioneer of single-groove stereo

Had vertical/lateral groove modulation won the battle for a stereo disc reproduction standard, Connoisseur might have been a leading record label and Arnold Sugden a leading figure in the industry. As it is, the company and its founder—pioneer of single-groove stereo recording—have drifted into obscurity. Reg Williamson looks at Arnold Sugden’s achievements.

*Reg Williamson is a visiting lecturer at the University of Keele.

Arnold Sugden—founder of Connoisseur and pioneer of single-groove disc recording.

For those of us active in high-quality audio engineering, the 1950s were exciting times. The tautological term ‘hi-fi’ had yet to find its way across the Atlantic, and the few commercial products that were available were produced by small specialist companies run by enthusiasts—among them Leak and Quad.

One such small company was Connoisseur, based in Brighouse, West Yorkshire. It was there, in 1953, that one of the most important steps forward in domestic sound reproduction was made, namely the single groove stereo disc. Sadly, the man who originated that development—Arnold Sugden—is now all but forgotten.

The idea of recording stereophonic sound on disc was not new. In the USA, Emory Cook was already establishing himself with his ‘binaural’ discs. These had a separate track for each channel. As a result, they required two pickups on the disc started simultaneously to reproduce the recorded material. Although they made it impossible to preserve phase coherence, Cook’s records were novel.

In 1933, the system that modern techniques are based on was patented by Alan Blumlein. He was working in the British laboratories of EMI—parent company of the familiar ‘dog and horn’ record label. Similar, but in my opinion less impressive work was also being carried out at Bell Laboratories in the USA. At the time EMI, with what was to become its ‘heritage’ pickup, was already developing a system of groove modulation, shown in the diagram. Paradoxically, most of EMI’s competitors demonstrated their enterprise by marketing records in that same year.

Blumlein’s patents languished until around 1958, when an international standard was eventually agreed using his proposed 45°/45° system of groove modulation, shown in the diagram. Paradoxically, most of EMI’s competitors demonstrated their enterprise by marketing records in that same year.

Blumlein’s old company however misguided placed all its commercial faith in 19cm/s two-track stereo tapes—the Stereosonic system. Inevitably, because of the cost of both the software and the hardware, it failed. Belatedly, the company conceded defeat and began to produce stereo long-playing records the same as those of its competitors.

Arnold Sugden was the enthusiastic managing director, technical director and owner of the Connoisseur company. For some time, the company had been enjoying considerable commercial success in producing many high quality record playing products.

One of Sugden’s most notable products was the first British belt-driven turntable. This subsequently became available in kit form and was an unusual introduction in the new market for such audio products. Even today, the BD1 turntable is much sought after by enthusiasts.

Practically everything to do with sound reproduction and recording was tackled by the tireless innovator. Connoisseur’s first post-war product designed by him was a miniature lightweight cartridge and arm for quality reproduction of the old 78rpm discs. He even invented a technique for mass-producing the miniature chrome-tipped steel needles that were in very short supply just after the war.

Pickup arms, cartridges, amplifiers, loudspeakers—even microphones—all appeared bearing the Connoisseur label. As early as 1950, Connoisseur was manufacturing a combined 33 and 78rpm turntable, a high-quality pickup with interchangeable heads and a twin-speed disc recording system.

This is the more remarkable when, as I learned during a visit to see Arnold Sugden, he had left school at fourteen and had never had any formal engineering training. But, from the outset of his career, he demonstrated a natural flair for engineering design of an intuitive kind that is all too rare these days.

An engineer with a passion for music Sugden’s interest in high-quality audio was, in common with many of us in those days, linked with a passion for music. This is no longer considered an essential pre-requisite. Shortly after the introduction of the long-playing record, he became convinced that there was a future for single-groove stereo on disc.

In 1953, he set to work in a disused church near the Connoisseur factory, often working alone until the early hours of the morning. He finally perfected a stereo head. It was designed to be fitted to a disc-cutting table the company had already developed.

By methods both intuitive and empirical—an approach that would be frowned on today—he evolved a remarkable design that one cannot easily fault. He already knew that the mass of the cutter had to be as low as practicable. This mass, linked with compliance of the movement, has to push the first fundamental resonance of the system as high as possible.

His use of balsa wood as the former materi-
al vividly demonstrates his unorthodox, but imaginative approach. With it he achieved a fundamental system resonance of 4.5kHz, and it was well damped. This he corrected by a tuned circuit in the driver amplifier.

An equally unusual feature of the system was its efficiency, requiring as little as 5W to fully modulate the cutter assembly. A heavy, powerful magnet was mounted separately on the cutter carrier. Only the comparatively light weight of the cutter assembly rested the stylus on the surface of the master lacquer disc.

A cartridge capable of playing his records had to be designed and made. Sugden's solution clearly demonstrates his uninhibited imagination. At that time, there was a very popular monophonic crystal cartridge. It was designed by Stanley Kelly for the Cosmocord company and called the Acos. It was very much ahead of its time, being the first crystal type with any claim to a wide frequency response and low tracking weight.

Sugden simply took two of these cartridges, mounted them together at right angles, and coupled the two styli with a fine wire link. He mounted this combination in a special moulding. As a short-term solution to an engineering problem, it was an extraordinary approach.

Inevitably however, later tests showed that its performance was markedly inferior to that of the cutter. So Sugden went on to design a high-quality crystal cartridge himself, which he marketed for the emerging 45°/45° discs.

First stereo demonstrations

By 1956, Sugden was ready to demonstrate his system. He had produced master tapes using spaced Neumann U47 capacitor microphones and a tape recorder fitted with a staggered head. Learning from his experience, Sugden later reduced the spacing in his miking technique. He used as little as 6in separating the pair and angled them outwards by approximately 90°. This basic configuration is still favoured today by some purists.

While he had finally decided on vertical and lateral groove modulation, his cutter could also be used for 45°/45°, given an appropriate matrix. Since doubts about the validity of Blumlein's original patents had emerged, the groove modulation had to be vertical/lateral, for the time being at least.

No conventions or standards existed at that time. On the basis that the most critical sounds should come from the string section of an orchestra, Sugden determined that the lateral cut should carry the left channel. Additionally, there appeared to be no advantage for any particular phase relationship between channels, so long as it was always consistent with the arbitrarily chosen standard. Incidentally, the lack of knowledge of what the original phase relationship was created some difficulty when attempts were made to re-matrix some of his original pressings for playback.

In the preceding three years, Sugden had recorded a diverse range of material locally. This included orchestral concerts, brass bands - a speciality of his native county, Yorkshire - and cinema organs. From this wide variety, he subsequently cut lacquer stereo discs.

Now, he looked for a platform to demonstrate his achievement to his peers. Commercial hi-fi shows of the kind common today were non-existent in 1956. Most new developments were demonstrated every year in London, at a two day exhibition. It was organized by what was then called British Sound Recording Society which was eventually absorbed into the AES British Section.

In audio advancements terms, 26 May 1956 was a particularly memorable date. At that same show, Sugden first introduced his stereo discs. Peter Walker of Quad also demonstrated his prototype electrostatic speaker - another significant development in audio design. As you might expect, there were many queues to hear these twin wonders, including me.

To put this into perspective, neither of the two major record companies in the UK were, at that time, showing any great interest in a disc system based on vertical/lateral or 45°/45° techniques. As mentioned earlier, EMI had placed its faith in tapes. Decca was working independently on an hf carrier system for vinyl discs, presumably to bypass the Blumlein patents, but with little urgency. In passing, the original Decca pickup was designed for this system and it is still popular.

To say Sugden's demonstration caused a stir would be an understatement. Almost immediately, he was besieged in Brighouse by all the record companies anxious to take advantage of his pioneering work. EMI even sent a large mobile recording studio to his factory, so that sample discs could be cut from a variety of early EMI stereo master tapes.

Many of these masters were subsequently pressed, revealing some difficulties in the pressing technique. The problems to overcome these too, were given a demonstration at the BSRA exhibition of 1957. Having acquired a pair of these pressings and using a suitable active matrix, I have been able to play them with an orthodox 45°/45° cartridge; and very impressive they are, too.

Even the record sleeves were ready

Had vertical/lateral recording been adopted as the standard, there might now have been a Connoisseur label on the market. Four discs were in fact prepared, ready for issue, and six more planned for release. Even the sleeves were designed by the enterprising Arnold. But it was not to be. Illness, probably brought on by overwork, slowed all progress on producing stereo discs. Eventually, it had to be dropped altogether when commercial stereo discs to the universally agreed 45°/45° standard were released in 1958.

As 'hi-fi' arrived and highly competitive, consumer-orientated products began to appear from the Far East, the viability of Sugden's company was diminished. In the early 1970s, Arnold Sugden sold his company and retired.

The final chapter in the story of his enterprise ends on a sad note, for the company fell into the hands of asset strippers. Now, the once familiar name of Connoisseur has disappeared and the historically-important hardware is lost - an unhappy, but all too common tale in today's commercial world of hi-fi.

However, not so for the name of Arnold Sugden. Within audio history, he has written his own personal paragraph and undoubtedly earns a prime place amongst the pioneers. Together with many of his contemporaries, he advanced the science and art of sound recording and reproduction to a significant degree.

In the preparation of this article I gratefully acknowledge the supply of drawings and much information from the veteran Arnold Sugden himself, now into his 82nd year and to whom I offer this as a warm tribute.
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Synchronous oscillators: Alternative to PLL?

The synchronous oscillator is a fascinating circuit to play with, offering as it does an alternative approach to the PLL for signal extraction in a noisy environment. The possible variations on the theme are limitless. Ian Hickman investigates.

The phase-locked loop is a tried and tested circuit, well understood, capable of extracting signals buried in noise. However, it is not the only way of pulling out a wanted signal from noise. An ISSCC report on the efficiency of the synchronous oscillator prompted me to investigate the circuit further.

It is well known that an oscillator can be synchronised with an external signal of the same (or very nearly the same) frequency. This applies to oscillators of all sorts so that, for example, a Wien bridge audio oscillator can be locked over a small range of frequencies to a signal injected into the maintaining amplifier. This signal does not need to be a sinewave; the oscillator will lock to a low-level squarewave while delivering its normal sinewave output... in effect a high Q filter.

At rf, a weakly oscillating LC oscillator can be used in a similar way - a scheme which under the name "reaction" (or, in the USA, the more colourful term "tickling") is as old as the hills. Where the synchronous oscillator differs from this scheme is in the means by which the external signal, to which it is desired to lock the oscillator, is injected.

Fig. 1 shows the basic circuit of a synchronous oscillator as it appears in Ref. 1 and several other of the referenced papers. Here, Tr2 is arranged as a Colpitts oscillator, with its emitter current supplied from Tr1's collector. In the absence of any external synchronising input, the oscillator runs at the frequency determined by its tank circuit. An applied external signal modulates Tr2 collector current to a lesser or greater extent, even chopping it up into pulses in the case of a large applied signal. This modulation will synchronise the oscillator if the injected signal is close enough to the free-running frequency, though with a standing phase difference between the injected signal and the oscillator's output of up to ±90° over the extremes of the frequency range for which lock is maintained.

Critical dc operating point

The stated theory of operation points out that the oscillator transistor Tr2 is designed to run biased well into class C, with a small conduction angle, with the result that it is insensitive to noise accompanying the externally applied signal for most of each and every cycle.

Anyone used to analogue design will instantly see some shortcomings in Fig. 1, in particular the very poorly defined dc conditions, due to the use of high resistance bias sources for two devices in series. The author of Ref. 1 states that the circuit is set up so that the transistors have equal collector-emitter voltages and thus both run in a linear regime. While it is possible to select transistors or bias-resistors or both to achieve this, tracking with varying temperature and aging cannot be guaranteed even with transistors of the same type. Indeed, some of the circuits in the referenced papers actually use different transistor types at Tr1 and Tr2.

From Ref. 1 it appears that the circuit is run from +5V, which leaves only 2.5V Vce for each device, assuming the biasing is perfectly balanced. Thus the maximum achievable tank circuit amplitude is about 4V peak to peak and the amplitude at the emitter of Tr1 will typically be a third of this. So the conduction angle will in fact be significant.

The circuit of Fig. 2 was therefore chosen for initial experiments. Here, the dc conditions are well defined, with the oscillator transistor's emitter current supplied from one half of a long-tailed pair. With the tank components shown, the free-running frequency was 893kHz. Fig. 3a shows the input waveform (lower trace) and the output (tank circuit) waveform with a signal input of 1V p/p at 875kHz (the lower end of the lock range) where the output is leading the input by 90°. Figs 3b and c show the same at 893kHz (input and output in phase) and at 919kHz (output lagging by 90°) respectively. Fig. 3d shows the output of the synchronous oscillator with a swept input frequency.

To maintain the light circuit loading provided by the 'scope probe, the spectrum analyser was not connected to the circuit directly, but driven from the oscilloscope's Channel 2 signal output, which provides a 50Ω output impedance. The input signal was swept from just above the lower limit of lock to just above the upper limit. At this point numerous FM
sidebands appear, mainly on the low frequency side, related to the rate at which the synchronous oscillator slips cycles in an unsuccessful attempt to retain lock.

Note that the amplitude of the oscillator's output is a maximum at the centre of the lock range, i.e. at the frequency at which it free-runs in the absence of an input. Ref. 6 states that this is a characteristic of an injection-locked oscillator, whereas in a true synchronous oscillator, the output amplitude is constant overall the whole lock range. Why the Fig. 2 circuit exhibits this departure from the expected synchronous oscillator performance I am unable to say.

Another aspect of the synchronous oscillator's characteristics is its ability to lock to an input frequency which is an integer multiple (harmonic) of its output frequency or a submultiple. This behaviour is shown in Fig. 4a and 4b respectively, again using the Fig. 2 circuit. In each case, the input signal amplitude was -10dB ref. 1V p/p. In 4a, the 890kHz output (upper trace) is locked to an input at three times that frequency, i.e. the circuit is operating as a divider. In 4b, the 890kHz output is locked to an input at one third of that frequency, i.e. it is acting as a tripler.

The apparent amplitude modulation of the output at one half of the input frequency is one of those little mysteries that crop up all the time in electronics. I would have pursued it further, but I began to feel that in some respects, the circuit of Fig. 2 departed from the basic synchronous oscillator philosophy. Thus, for example, unlike the SO of Fig. 1, the circuit will not readily act as a doubler, quadrupler, etc., since the balanced nature of the LTP stage feeding the Colpitts oscillator results in a minimal level of even harmonics in its output.

It was time to look at the synchronous oscillator circuit as published in Ref. 1.

**Is it a synchronous oscillator?**

I constructed a version of the basic synchronous oscillator circuit of Fig. 1 with Tr1 and Tr2 both 2N918s (selected for equal hFE), G=220kΩ, Gb=100kΩ, L=14μH, C1=4n7, C2 and C3 both 100p and Le = 22μH. This gave an operating frequency of around 6MHz, with a +5V supply rail.

Although the two transistors operated with approximately equal values of Vce, the oscillator transistor was bottoming heavily, viz. not operating in a linear regime. The two bias resistors were raised first to 1M and 470k, then 2M2 and 1M, but still the oscillator bottomed. Clearly the operating dynamic resistance Rød...
of the tank circuit was rather high, despite the heavy loading set by equal values for C2 and C3, but other worries about the circuit were beginning to niggle. For instance, although C2R in conjunction with the hfe of the oscillator transistor sets the mean or dc value of the base potential, rf-wise, the base voltage can flap about. T/R has a high output resistance and so will not define T/R’s emitter potential, while the presence of the rf choke means that the top end of the tank is not clamped to the supply rail voltage (rf ground).

Is the rf choke really necessary, and if it is, what defines the rf voltage at the ends of the tank circuit – and hence the voltage delivered to GL, which in my case was a ‘scope probe? Doubts about the choke were confirmed by Fig. 8 of Ref. 1, where a 10pH rf choke is used in a circuit operating at 560MHz. The reactance of an ideal 10pH inductor at 560MHz is over 35kΩ and it would resonate with a capacitance of just 0.008pF. Thus the impedance of the (unspecified) 10pH rf choke at the circuit’s operating frequency is anybody’s guess. Incidentally, this “improved” synchronous oscillator circuit has a bias source for the lower transistor consisting of 11mV from a 5kΩ source, so that in the absence of an input of considerable amplitude, the lower transistor will be cut off, supplying zero emitter current to the Colpitts oscillator transistor.

On to a new circuit for investigation, Fig. 5a. As in the published papers.

Fig. 5a. Modified synchronous oscillator circuit with robust definition of dc conditions. b. Gain and bandwidth of a synchronous oscillator as reported in the published papers.

Fig. 2, the oscillator transistor’s emitter current is closely defined, while the emitter of the lower transistor is at ac ground as in Fig. 1. With no external input, the circuit oscillated at about 6.5MHz, with 10V p/p at the collector of the upper transistor, a little over 2V p/p at the emitter, Fig. 6a.

The double exposure also shows the ‘scope inputs grounded, indicating the emitter reaching a peak negative-going excursion of -0.8V relative to ground (upper trace) and the collector voltage swing centred about the +10V rail. Thus the oscillator transistor operates with a narrow conduction angle and the collector voltage well clear of bottoming at all times.

I hoped it would reproduce the performance shown in Fig. 5b, which indicates the gain of an synchronous oscillator versus input level as described in the references. Incidentally, Fig. 6b shows the typical performance of an oscillator when the mean emitter current is not controlled to a level appropriate to the dynamic resistance of the tank circuit. Not only does the base emitter junction become forward biased, but the base collector junction does likewise at the negative extreme of its excursion. It thus appears as a forward biased diode connected directly across the tank circuit, providing heavy damping which reduces the effective operating Q.

The waveforms shown here resulted from a lower value of resistor (10kΩ) in the emitter of the lower BFY90 in Fig. 5a, but are typical of the result when an oscillator circuit provides the active device with a fixed base current. High gain samples of the oscillator transistor will try to pass more collector current than is appropriate, and the negative going collector swing then mops up the excess base current, charging the associated base capacitors negatively in the process.

The result is an overlong conduction angle, as shown.

Figure 7a shows the output of the synchronous oscillator circuit of Fig. 5 as a 0dBm input is slowly swept over a 500kHz range centred on 6.7MHz. At the start of the sweep, the oscillator is not in lock and so runs at its natural centre frequency, producing a bright trace there, while the applied frequency can be seen to be well down the skirt of the tuned circuit. However, as the sweep proceeds, the amplitude of the applied signal does not trace out the shape of the tank circuit’s response curve. But suddenly jumps up to the same level as the oscillation, as the latter synchronises with it.

The lower level responses that are visible are due to the various out-of-lock sidebands seen in Fig. 3d: they would not have been visible if a spectrum analyser with a built-in tracking generator had been used. However, the top of the trace indicates the output at
the wanted frequency, whether in lock or out. Figs 7b and 7c show the synchronous oscillator output with the input reduced from 0dBm to -20dBm and -30dBm respectively. The result with -10dBm was intermediate between the two.

Since the amplitude of the synchronous oscillator output in lock is independent of the level of the input, it follows that the smaller the input, the larger the "gain" to the signal. Fig. 7d shows tracings of the results in 7a-7c superimposed such that the edge of screen levels are aligned, illustrating this point and giving the same sort of result as in the published papers.

At 0dBm input, the lock range was 105kHz or 1.56% of the centre frequency, and 0.62%, 0.21% at -20dBm, -30dBm respectively. The acquisition of lock appears to be virtually instantaneous, unlike a second order PLL using a simple ex-OR phase detector, where the time to acquire lock may run to many cycles of the input.

Acquiring signals in noise
My tests to date have only covered the performance of the synchronous oscillator with a clean CW input - a very high SNR (signal to noise ratio) - whereas one of its main uses is said to be recovering a signal accompanied by noise. It seems that they are not ideal for recovering signals deeply buried in noise, Ref. 4 stating that the types experimented with and employed in various digital radio subsystems are not used below $E_b/N_0=-3$dB. I intend carrying out further tests in conjunction with a suitable noise generator, which will entail building a permanent version of the circuit reported in Ref. 7.

It was my hope that the synchronous oscillator would prove suitable for pulling out a signal with a large negative SNR that prompted the use of an LTP in Fig. 2. With suitable emitter degeneration, the LTP would modulate the input signal plus noise onto the oscillator's emitter current in a linear manner. This is
important, since with a large noise voltage applied to the LTP (and no degeneration) the signal plus noise input would in effect be hard limited. Now, while hard limiting a signal well above noise improves the SNR by 3dB, hard limiting a signal buried well down in noise makes it 3dB worse. Perhaps this is the reason for the limited performance of the type of synchronous oscillator shown in Fig. 1, where there are no specific measures to linearise the transistor forming part of the signal injection network.

Ref. 6 quotes results with inputs up to 0dBm which, in a 50Ω system, corresponds to 636mV p/p. This is certainly more than the injection transistor (with no emitter degeneration or other linearising measures) can be expected to handle linearly. In fact, the transistor will start to bias itself back towards class C, so that both it and the oscillator transistor operate in a sampling mode. But with a negative SNR, this sort of limiting (by "dc restoring" the signal negative going) probably risks suppressing the wanted signal energy even more than the symmetrical hard limiting produced by an LTP.

The synchronous oscillator shares with the PLL a difficulty in giving a reliable in-lock indication with acquired signal. In a PLL used in a high SNR application, e.g., in a synthesiser, a lock detector often comes for free in the phase detector chip, along with an edge triggered "Type II" phase detector for rapid lock acquisition. However, in a PLL used for recovering a signal buried in noise, edge-triggered logic-machine type phase detectors don't work and must be replaced with an ex-OR variety, with the smaller ±90° phase range. With this type of phase detector, the pull-in time can become quite long especially at poor signal to noise ratios. (The distinction between pull-in range and lock-in range is explained in Ref. 8, which further states that the distinction between the two can become rather blurred if appreciable noise is present in the circuit.) It will be interesting to see if the synchronous oscillator still locks up instantly to a wanted signal buried in noise.

References
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Measuring pulses digitally

Frequency meters normally count the number of unknown waveform cycles occurring during a known reference time period. For higher frequencies, such cycle counting is fine. Given a 0.1s reference gating period and a 1MHz signal under test, it is possible to produce a measurement with a resolution of $10^5$ in 0.1s. Reading a 1Hz signal to the same resolution however would need a 100,000s gating period – and a wait of more than a day for the result.

Rather than using a reference period to gate the input signal, as in a conventional frequency meter, pulse-width measurement schemes use a single cycle of the unknown input pulse to gate multiple cycles from a reference clock at a higher frequency. Width of the unknown pulse is directly proportional to the number of reference cycles counted during the gate period. Frequency is simply the inverse of this reading.

Where the unknown pulses are quite wide, or high resolution is not essential, microcontrollers with on-chip counter/timers provide a single-chip solution. Speed is limited by clock dividers within the microcontroller. Maximum clock rate for counter/timers in an 8051 controller running at 12MHz for example is only 1MHz. In addition, microcontrollers are expensive to develop and implement. Standard logic ICs provide a faster solution but significantly increase the number of components needed.

Two dedicated ICs recently launched by Numa have been designed to produce a digital output reading representing an unknown input pulse width. Called the NT302 and NT304, these period-to-digital ICs provide binary counts of up to $2^{12}$ and $2^{16}$ respectively. Maximum frequency of the external reference clock is 125MHz while the maximum rate for extracting data from the first-in-first-out register is 10MHz.

Within the NT302 are two 12-bit counters, gating circuits, latches for the data and control logic. As shown in the block diagram, there is also a 32 by 12-bit first-in-first-out register common to both channels and a clock divider stage with four external outputs for driving, say, a DSP chip. The two input channels accept complementary C-MOS compatible input signals. Only one other input is needed – the reference clock.

Reference clock

Clock frequency is simply:

$$F_{\text{clk}} = F_{\text{in(min)}} \times 4095$$

where $F_{\text{in}}$ is the input signal.

Sampling of the first and second half cycles, namely $t_{pwh}$ and $t_{pw1}$, is alternate. The 12-bit binary number representing the first half cycle is given by:

$$N_1 = t_{pwh}/(1/F_{\text{clk}})$$
and for the second by,
\[ N_2 = \frac{f_{pw}}{1/F_{clk}}. \]

For the whole period, the 12-bit binary number becomes simply,
\[ N_{tot} = N_1 + N_2 \]
or
\[ N_{tot} = (f_{pw} + f_{pw})/1/F_{clk}. \]

Once clock frequency is found, the minimum input frequency is established. This frequency causes a count of 4096. Should the frequency fall lower, the counters will overflow producing a false result.

In the circuit diagram is a zero-crossing detector which ensures correct operation of the NT302. On the left is a regulator producing a fixed 2.5V reference. This voltage may vary depending on the application. Input is capacitor coupled to inverting input of the first op-amp, whose gain ensures that the input wave-form is square. Next, the comparator produces the complementary waveform necessary for the NT302.

On a high-to-low transition at the NT302's Q inputs, the count is transferred from the 12-bit counter to the data latches then into the fifo. Next, the counters are reset and the system samples the next half cycle.

Latching and resetting takes approximately eight reference clock cycles and continues as long as there is an input signal. Maximum duty cycle of the input signal becomes a function of the eight clock cycle transition time and is given by,
\[ DC < 1 - \frac{8(f_{pw})}{T} \]
where is is \( f_{pw} \) is 1/F_{clk} and \( T \) is 1/F_{in}. For an input frequency of 1MHz and a system clock of 100MHz, maximum duty cycle would be 92%.

Data in the fifo is shifted out on a falling edge at the READ input. If data is present at the fifo output, the data-available line, DA, goes active low. In the event of no data, DA remains high, allowing the presence of valid data to be signalled to software or hardware. Since there are two zero crossings per cycle, data can be extracted from the fifo at twice the rate of the input frequency.

The two counters are enabled alternately and there are two zero crossings per cycle. This means that 12-bit binary numbers representing each half cycle are extracted from the fifo alternately. They can be added to produce a period result, divided to define duty cycle or used as an address to access a look-up table.

Sending the data to a digital-to-analogue converter provides an analogue representation of the binary word. Relative to analogue pulse-width measurement techniques, this digital approach results in an accurate and linear analogue signal which is highly immune to DC offsets and temperature drift.

**Novel fm demodulator**
This approach to fm demodulation is said to be unique. Incoming fm analogue signals are amplified by a high-gain IF stage in which fm square waves are produced by limiting action.
Results obtained from a new approach to fm demodulation. Applying a high gain stage to the incoming IF information produces squarewaves that can be sampled by the period-to-digital chip with the aid of a high-speed system clock. These digitised samples then feed a digital signal processor which uses estimation techniques to produce frequency-demodulated audio data. Part of the processing involves a technique called reciprocal count scaling. In addition to being high quality, the output also has a high signal-to-noise ratio.

Using high-speed clock and counting circuits, the square waves are digitised into binary counts. These counts are sampled and sent to a digital signal processor without using any analogue-to-digital conversion. Counts are subsequently processed in the DSP system using estimation. Noise is said to be inherently low since the technique has a noise limiting as opposed to the noise additive effect common in traditional analogue fm demodulators.

Under the proposed demodulation technique, incoming IF is squared then sampled directly to obtain its zero-crossing information. Digitally encoded, this information is fed to DSP chip where the modulating signal is extracted using a reciprocal count-scaling software routine. Extracted signal can be further digitally filtered before being passed to a digital-to-analogue converter. Adopting reciprocal count scaling for demodulation is said to guarantee the most accurate results attainable from a system of this type in terms of s-to-n ratio, harmonic distortion and scaling accuracy.

Digitised count information is produced so that the lowest number of reference clock counts for a given sample corresponds to the highest modulating signal amplitude. Conversely, the highest clock count represents the lowest modulation amplitude.

Numeric processing hardware in the demodulator system receives a binary representation of fm data directly from the zero-crossing circuitry in the IF strip. Estimations are made of successive digital samples. An application article entitled DSP peripheral IC does period-to-digital conversion is available from Clere Electronics at Kingsclere in Newbury, Tel. 0635 298574, fax 297717. It includes full design equations for the fm decoding technique.

Algorithms for implementing the new fm decoding method are also available to design engineers. These are based on the Analog Devices 2100 DSP family.

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Date (UK) Ltd. Tel., 0256 880444; fax, 0256 880706.

Linear integrated circuits

RF/video switch. Siliconix’s DG64X series video switches exhibit low B over resistance, the DG643, for example, offering, present only 8u with an on-state capacitance of 10pF. Bandwidth to –3dB is 500MHz and current-handling ability, 75mA. Packaging is SO-16 or 16-pin dip. Siliconix/Temic Marketing, Tel., 0344 485757; fax, 0344 427071.

850MHz buffer. An 850MHz buffer amplifier by Harris, the HFA1114, is intended for video and instrumentation work and eases the problem of holding the full bandwidth over long cables by allowing access to the summing junction at the internal amplifier’s inverting input, so that compensation networks are more easily and effectively applied. The amplifier also allows gain programming to +2, +1 and −1. Salient characteristics are 1500V/μs slewing at a gain of ±1, 2400V/ps at +2, 11ns settling time to ±1 and 1900V/ps at +2, 11ns settling time to 0.1%, gain flatness to 30MHz and 0.07dB to 100MHz. Output current is 60mA. Harris Semiconductor UK. Tel., 0276 688886; fax, 0276 682323.

50Ω pulse amplifier. Bandwidth of the Mini-Circuits ZPUL-21 50Ω, 24V-350mA pulse amplifier is 2.5kHz-700MHz and it is usable up to 1GHz with a flatness of ±0.6dB. Rise and fall time is 1.1ns and delay time 1.5ns. Mini-Circuits Europe. Tel., 0252 835094; fax, 0252 837010.

GaAs switch. GSWA-4-300V is a gallium arsenide switch from Mini-Circuits with a bandwidth of 0-3GHz. It switches at 25ns and isolation is 30-40dB to 3GHz. video leakage to 50Ω RF ports 20mV/pk-pk typical in 500MHz bandwidth. Mini-Circuits Europe. Tel., 0252 835094; fax, 0252 837010.

PWM controller. UC3848 by Unistro is the first family of current-mode PWM controllers designed for single switch forward converters, allowing primary-side control of secondary-side current in isolated switching power supplies. It offers low peak average current ratio low ripple current and a start-up current of 500μA. It copes with continuous or discontinuous inductor current, allowing a smaller inducer. During switch-on the device monitors current switch current and synthesises inductor current down-slope to simulate inductor current during switch-off. Unistrode (UK) Ltd. Tel., 081 318 1431; fax, 081 318 2549.

Logic building blocks

Automotive relay driver. Zetex’s avalanche-rated ZVN4206AV n-channel mosfet is designed for automotive use and removes the need for driver-relay interface and protection. It supports a drain-source voltage of 60V and exhibits an on-resistance of 12μ, operating from a 5V gate drive. Although the device will drive 600mA coils, it needs no catch diodes, all energy being dissipated through avalanche breakdown of the intrinsic body diode, which also handles reverse-battery accidents and 50%, 65V load dumps. Zetex plc. Tel., 061-627 5105; fax, 061-627 5467.

16-bit bidirectional buffer. Combining the functions of two transparent octal latches and an 18-bit wide 4-deep fifo in one 56-pin package. IDT’s FCT162701T has a propagation delay of 5.5ns and solves the bandwidth mismatching between CPU and memory or CPU and I/O in 84400/84600, Pentium and PowerPC applications. It also saves around 80% of board area and reduces the number of ICs by eight to one. The 162701T allows zero wait-state working up to 75MHz and more than doubles system performance. Ground bounce is less than 600V.

Integrated Device Technology. Tel., 0372 363734; fax, 0372 378851.

Clock distribution. Output skew of the TI CDC330 clock distribution circuit is 0-0.5ns maximum and the processing skew 1ns maximum. Maximum clock frequency is 67MHz for two 1-to-3 paths and 100MHz for the divide-by-two path, both for a duty cycle of 40-60%, all these figures for a maximum output current of ±32mA. Each set of outputs per path is individually switchable into tri-state. Texas Instruments. Tel., 0234 270111; fax, 0234 223459.

Memory chips

Low-voltage memory. Made by Micropich, the 24A4xx family of 1.8V serial eeproms in 1K, 2K, 4K, 8K and 16K versions draw only 50μA read current and 3μA on standby. They operate over the full voltage range of two AA batteries, which have an end-life of around 200000 cycles. Features include Schmitt trigger inputs, output slope control to eliminate ground bounce and user-selectable write protection. They also have a page-write buffer holding up to 16 bytes.

Polar Electronics. Tel., 0552 377033; fax, 0552 378367.

Microprocessors and controllers

Printer chip, 68322 from Motorola is the first in a series of microprocessors intended for use in low-cost printers. It is a single-chip, dual-processor device with a full DMA, eight page-per-minute, 600 DPI PCL/Postscript laser printers, but is also suitable for multifunction peripherals, inkjets, and other general embedded applications. The 68322 offers graphics acceleration on the one chip and is a replacement for current 68000 designs with companion asics. The device supports bi-directional data transfer between the CPU and memory or CPU and I/O in 84400/84600, Pentium and PowerPC applications. It also supports various I/O operations such as UART, SPI, and I2C for communication with other members of the family.

Hitachi’s H8/3048 is a variant of the company’s H8-300H series of 16-bit microcontrollers, which has, says Hitachi, the largest on-chip memory in the world at 128K of rom and 4K of ram. It offers a high-performance CPU that goes up to 1.8Mips in a 3-layering design with run-time clock operating at 16MHz and a large linear memory format allowing greater flexibility while maintaining compatibility with other members of the family.

For use in GSM handsets, there is a serial port to the GSM subscriber interface and several power-down modes of operation. On-chip peripherals include inputting timing provision devices such as input multiplexers and output buffers to drive three-phases motors. There are also a full DMA controller, a 16-bit bipolar A-to-D converter, 8-bit bipolar D-to-A converter and a Watchdog timer. A timing pattern controller connecting the DMA, timer unit and output to drive three-phase motors. There are also a full DMA controller, a 16-bit bipolar A-to-D converter and a Watchdog timer. A timing pattern controller connecting the DMA, timer unit and output to drive three-phase motors. There are also a full DMA controller, a 16-bit bipolar A-to-D converter and a Watchdog timer. A timing pattern controller connecting the DMA, timer unit and output to drive three-phase motors.

Hitachi Europe Ltd. Tel., 0229 556500; fax, 0228 585200.

Low-power 0.5um embedded array

3V cmos embedded arrays in 0.5μm technology from Toshiba now offer the option of 5 working. TC182E has the same ccre as the 3V TC180E series, having gate propagation delay of 0.25μs and is claimed to outperform 3.5μm, 5V asics. Each i/o pin is individually programmable from a library of 3V or 5V interface cells. The devices have a page-write buffer holding up to 16 bytes. Toshiba Electron. Co., Ltd. Tel., 0372 363734; fax, 0372 378851.

Clock distribution. Output skew of the TI CDC330 clock distribution circuit is 0.5-0.5ns maximum and the processing skew 1ns maximum. Maximum clock frequency is 67MHz for two 1-to-3 paths and 100MHz for the divide-by-two path, both for a duty cycle of 40-60%, all these figures for a maximum output current of ±32mA. Each set of outputs per path is individually switchable into tri-state. Texas Instruments. Tel., 0234 270111; fax, 0234 223459.

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Low-power microcontrollers. Low-power, 8-bit microcontrollers in Fujitsu's MR97210 and MR97210 series use the same CPU as other members of the CMOS 8L line, taking a current of only 0.5mA at 3V and 4MHz, although the devices operate from 2.2V to 6V. MR97210 offers on-chip 4Kbyte rom, 128byte ram, a watchdog timer, synchronous serial interface, two clocks for 4.2MHz and 32MHz, two cascadable 8-bit timers/counters and 36 i/o circuits. The MR98910 does all that plus a 4-channel A-to-D converter with a 4.2us conversion time. Fujitsu Microelectronics Ltd. Tel., 0628 76100; fax, 0628 781484.

Multimedia processor. Claimed by TI to be the highest-performing DSP available, the Multimedia Video Processor (MVP) delivers over two billion operations/s based on risc-like instructions, which is the kind of performance needed for microprocessors in the video world. The device is based on TI's TMS320 DSP family and contains four DSPs and a risc processor on the same chip. It is fully programmable and supports MPEG, JPEG, H.261 and G.722. Texas Instruments. Tel., 0234 270111; fax, 0234 223459.

Mixed-signal lcs
RF preselector. RF portable telephone preselector µP152025R2 by NEC operates from 0.5GHz to 2GHz, consuming 2mA from 3V. Division ratios are 64, 65, 128 or 129:1. NEC Electronics (UK) Ltd. Tel., 0908 691133; fax, 0908 670290.

Optical devices
Optical-fibre switches. AMP's Kaption ranges of optical-fibre switches are for general and FDDI installations and provide losses of less than 0.5dB. They come in single-pole, double-throw and DDT formats, the PC-mounting general-use types being 5V operated. The FDDI version conforms to FDDI and IEEE 802.3, being a fully reversing bypass switch that allows faulty modes in a Token Ring network to be isolated. In bypass mode, a self-test path enables the transmitter to be tested against its own receiver while maintaining less than 0.5dB loss in the external network. Aurora (Europe) plc. Tel., 0908 274220; fax, 0908 378998.

130nm laser diode. For use as a light source in short and medium-range optical-fibre communications, Hitachi's HL1325CN is a 130nm InGaAsP Fabry-Perot laser diode in a coaxial package with a single attached fibre. Threshold current for an output at 25°C is 10mA, so that there is no need for additional cooling. Output power is 3mW pulse, 3mW continuous, reverse voltage 2V, rise and fall time 500ms maximum and monitor diode dark current a maximum of 350nA. Hitachi Europe Ltd. Tel., 0628 585000; fax, 0628 585200.

High-brightness leds. New from HP are the HLM-PV500, HLM-VL00 and HLM-VL100 leds for use in outdoor displays, colours being green, amber and red respectively. Luminous intensities at 20mA are 270mcd, 460mcd and 1000mcd, all the devices radiating a 60° horizontal angle and 30° vertically. Hewlett-Packard Ltd. Tel., 0344 362277; fax, 0344 362269.

Oscillators
Miniature oven oscillators. IXCO miniature ovened crystal oscillators in 14-pin dip packages by Stanler use the company's own crystals and switch the 10kHz-24MHz frequency range. Power used is 25mA from 12V at 25°C, 70mA being needed for the first 10s after switch-on. The units are in specification after 30s, ageing at the rate of ±0.7%/year and ±5ppm in 10 years. Stability is ±20ppm over ±0.3°C. The range has been designed with the aim of providing any level of output, within reason, at a fair cost. The company says its LS450 is made at a price to compete with offerings from the Far East, and points out that extended lines of communication can cause problems that are not solved by manufacturing in the UK. Gardners Ltd. Tel., 0202 482284; fax, 0202 470805.

Switched-mode power supply
Better known for its transformers, Gardners Ltd has introduced the first in a planned new range of switched-mode supplies for the medium-voltage European market, which will offer outputs from 15W to 100W in open-frame, lead-in, lead-out, plug-in and encased forms. LS450 is made at a price to compete with offerings from the Far East, and points out that extended lines of communication can cause problems that are not solved by manufacturing in the UK. Gardners Ltd. Tel., 0202 482284; fax, 0202 470805.

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Crystals

50MHz ceramic resonators. Murata has extended its frequency band of ceramic resonators - a lower-cost alternative to crystals - from 32MHz to 50MHz. They are now available in the standard frequencies of 33.66MHz, 40MHz and 50MHz for use in cordless telephones, CD and digital cellular equipment and are also available to specific requirements up to 60MHz to special order. Initial tolerance on the circuit devices is ±0.5%, or down to ±0.2% to order, temperature drift being less than ±0.3% between -20°C and 60°C. Resonator impedance is 40Ω or less. Murata Electronics (UK) Ltd. Tel., 0252 811666; fax, 0252 811777.

SM crystals. HC49U/54SMX is a surface-mounted version of the established HC49/4H crystal package, measuring 4.9mm by 13mm and 4.3mm high. Frequencies available lie in the 3.2MHz-50MHz range, with frequency tolerance and stability in the operating temperature range of ±50ppm and ±100ppm, although tighter specifications can be supplied for many frequencies. Load capacitance is 5-7pF, shunt capacitance 2-9pF and drive level 10μW minimum.

ICD Ltd. Tel., 0460 77155; fax, 0460 72578.

Small crystals. Seiko Epson's CA-303H mini-cylinder quartz crystal now operates over the temperature range -40°C to 85°C, with a range of specifications covering a range of frequencies. The package measures 8.9mm long and 3.1mm in diameter.

Advanced Crystal Technology. Tel., 0635 528520; fax, 0635 528443.

Displays

Bright multi-led indicators. Indicators using bright led arrays for sunlight viewing combine the brightness of tungsten filament elements with the long life of semiconductors. The Dialight 556 series provides the option of red, yellow or green with brightness of tungsten filaments with an insertion loss of 3.5dB. out-of-band attenuation of over 50dB per channel, so that non-repetitive events can be captured events down to 5ns in its full 4kword memory. Timing resolution is 2.5ns. In synchronous acquisition, a 50MHz logic anayser captures events using 4kword memory, enabling simultaneous capture of up to 160 events. The 25 automatic measurements and 25 programmable conditions. Features of both include slew-rate triggering and better than 50ps time accuracy, plus the latter having digital screen readout. Thurlby Thandar Instruments Ltd. Tel., 0480 412451; fax, 0480 450409.

Instrumentation

EMC measurement. A 1GPA impedance stabilisation network, the LISN1600 by Thurlby Thandar, enables accurate measurement of EMC emissions at the supply input of any electrical equipment operating from a single-phase supply. It meets the CISPR16 requirements for Band A in the 10kHz-150kHz range and Band B from 150kHz to 30MHz. A switchable 150kHz filter limits LF signals for Band B measurement, thereby reducing the required dynamic range. The measuring circuit is connected to either supply line or can be disconnected for checking the noise floor.

Thurlby Thandar Instruments Ltd. Tel., 0480 412451; fax, 0480 450409.

Low-cost oscilloscopes. New instruments from Goldstar are the OS-9020A, OS-9040D, OS-904RD and OS-3020, the lowest price being for the 20MHz dual-trace 9020A at £229.75 plus vat. This, the 9040D 40MHz type at £340 and the 904RD at £425 are all analogue instruments, the latter having digital screen readout. At the top of the range is the 2020 20MHz digital storage oscilloscope at £699.

MPS Electronics. Tel., 0702 554171; fax, 0702 555935.

Clamp-on multimeters. New from ITT is a range of clamp-on multimeters which measure voltage as well as current using four and smart power in PWM and other non-sinusoidal waveforms. MX210 and MX215 measure current up to 200A RMS, other functions being fundamental frequency of current and voltage, total RMS voltage and current, RMS voltage of fundamental voltage and current, total apparent power and effective power at the fundamental. Filters exclude switching frequencies for measurement up to 100Hz and a 1V FS analogue output proportionally, therefore the current levels are switched from instantaneous to RMS. Jaw size is 23mm.

ITT Instruments. Tel., 0753 511799; fax, 0753 694963.

400MHz logic analyser

At a maximum asynchronous sampling rate of 400MHz, ITT's TA4000 logic analyser captures events down to 5ns in the full 16kword memory. The 25 automatic measurements and 25 programmable conditions. Features of both include slew-rate triggering and better than 50ps time accuracy, plus the latter having digital screen readout. Thurlby Thandar Instruments Ltd. Tel., 0480 412451; fax, 0480 450409.

1GHz digital real-time oscilloscope. Claimed by Tektronix to be the world's first 1GHz digital real-time oscilloscope, the TDS664A is part of a new range of equipment for the development of advanced digital systems. It provides four channels of 1GHz, single-shot data capture, sampling at 5GSample's simultaneously on each channel, so that non-repetitive events are captured at full bandwidth. There are 25 automatic measurements and 25 programmable conditions. Features of both include slew-rate triggering and better than 50ps time accuracy, plus the latter having digital screen readout. Thurlby Thandar Instruments Ltd. Tel., 0480 412451; fax, 0480 450409.

Literature

AFDEC members guide. The Association of Franchised Distributors of Electronic Components has published its 1994 Members and Products Guide for 1994, in which nearly 60 UK distributors have their products listed, with telephone and fax numbers. Any value-added services such as assembly work and testing are mentioned. The guide is free.

AFDEC. Tel., 0763 27109; fax, 0763 273 256.

Valve and photodiode Spice models. Several application notes in the February Intusof Newsletter are concerned with Spice modelling of 12AU7A double triodes, EL9000 pentodes, BPW34 semiconductor photodiodes and photodiodes in general. Also described is the interactive ISSPICE4 program for Windows 3.1, Windows NT and the Macintosh. A disk containing all circuit diagrams and Spice models described is on offer.

Technology Sources Ltd. Tel., 0638 561450; fax, 0638 561721.

Harris power. Full specifications of Harris's power devices are given in a new Databook, which describes ultrastall and hyperfast recovery diodes, the MCT class of most controlled thyristors and insulated-gate bipolar transistors. Application notes included describe the use of IGBTs, MCTs and fast diodes, motor control and power supplies. Among the diodes described are some operating at up to 1200V and 150A.

Harris Semiconductor UK. Tel., 0276 688886; fax, 0276 682323.

3.3V SM power supplies. Offering single, 3.3V outputs, BICC-Vero's PK60K gives 15A and the PK240K5A, both at 3.3V, the PK240K giving a front-end filter for use in harsh conditions. Features of both include 110V to 240V ac input, ±0.05V ripple regulation, ±0.2% and remote on-off switching, PK60 in a 3U Bay and the PK240K in a 2U Bay with 60W or 140W type, both being compatible with DIN14494 backplanes.

BICC-Vero Electronics Ltd. Tel., 0489 760787; fax, 0703 264159.

Inductorless DC-to-DC converter. LTC1144 is a switched-capacitor voltage converter that accepts inputs from 2V to 18V and generates −2V to −18V. It is primarily intended to provide −18V from a positive input in automotive, automotive or in battery systems with chargers and in data acquisition, and is effectively a higher-voltage upgrade for LTC1044 and ICL7660 devices. Only two external, non-critical capacitors are needed for charge-pump and charge-reservoir system.
functions. The device runs at 10kHz from its internal oscillator, slowing down with an external C, and an ultrasonic frequency can be obtained by using the boost pin. Typical power efficiency is 95% and quiescent current 9uA.
Linear Technology (UK) Ltd. Tel., 0276 677676; fax, 0276 64851.

SW DC-to-DC converters. Newport Components' range of IS9001-approved converters provides output powers of 250mW-SW and are among the smallest available, measuring 19.5 by 7.5 by 10mm, some of the various package styles being surface-mounted and suitable for reflow soldering. There are 450 different models from 3V-48V in single and dual versions. Isolation is 1kV.
XP plc. Tel., 0734 84545; fax, 0734 843413.

Switches and relays
Stackable pushbutton switch. From EAO-Highland is the Grayhill 32 series of miniature pushbutton switches, which are stackable to allow custom switch assemblies on 0.2in centres. The switches have an internally sealed plunger and are compatible with flow-soldering and cleaning operations. Status/reset or press-to-test functions are provided, with led indication. Single-pole/single-throw normally open and normally closed packages are in the same package.
EAO-Highland Electronics Ltd. Tel., 0444 236000; fax, 0444 236961.

thrown normally open and normally closed. Single-pole/single-press-to-test functions are provided, compatible with flow-soldering and internally sealed plungers and are series of miniature pushbutton.
EAO-Highland is the Grayhill 32 Stackable pushbutton switch. From 843413.
dual versions. Isolation is 1kV.
soldering. There are 450 different models from 3V-48V in single and suitable for reflow various package styles being surface-
connected stages of filtering, amplification, mixing and the differential band-pass filter virtually eliminates the effects of magnetic and system offsets and confers a degree of immunity to RF interference. Two versions cover the −20°C to 85°C and −40°C to 125°C ranges.
Allegro Microsystems Inc. Tel., 0932 253355; fax, 0932 246262.

Pressure transducers. Subminiature versions of Kulite's LQ-080/125 thin-line pressure sensors, the LQ-060 series, measure 1.6 by 4.7mm by 0.4mm high, with a view to mounting them on turbine blades and other aerodynamic profiles. The sensors are available in pressure ranges between 25psi full scale and 200psi. Excitation is 5V or 10V and nominal pressure output is 100mV.
Kulite Sensors Ltd. Tel., 0256 461646; fax, 0256 47951.

New Mathcad versions
Mathsoft has announced new versions of its Mathcad calculation software. Mathcad 5.0 and Mathcad PLUS 5.0. Mathcad 5.0 is now easier to use and is provided with extra functions such as trace and zoom for graphics, print preview and a technical spell checker. Mathcad PLUS 5.0 has the same features, but also has an extensive number of functions such as differential equation solvers and advanced algebra matrix for more advanced users.
New features in Mathcad 5.0 include easier equation and text editing with pull-down menus and a function list, an on-line tutorial, new numeric functions including roots of polynomials and 2-D curve fitting and DDE support. For Mathcad PLUS 5.0, new algebraic functions include determination of matrix decompositions, finding eigenvalues and a complete matrix analysis system. Users may write their own routines in C or C++ or use Function Packs from Mathsoft.
Mathsoft Europe Ltd., Tel., 0444 234981; fax, 0444 873461.

SIP relays measure 3.81mm by 15.24mm by 6.6mm high and are in single-pole normally open form, rated for over 10⁶ operations at low loads. They have 5V or 12V coils and handle up to 10W. Options include a diode and/or magnetic shielding.
Coto Europe. Tel., (Netherlands) 01031 45 328088; fax, 01031 45 328038.

Transducers and sensors
Gear-tooth sensor. Allegro's type 0535 AC-coupled Hall-effect sensor is for the non-zero-speed sensing of ferrous targets and incorporates a voltage regulator, two quad functions.

Computer board-level products
Peripheral interface. PC326A from Amplicon Liveline is a programmable peripheral interface board using the 68256 IC to give 24 TTL-compatible digital I/O lines by way of a single 37-way type D connector. The lines are at three levels: inputs, two of which are programmable to be all inputs or all outputs, the third being four inputs and four outputs, if required. A lower-power version for laptops is available, both types coming with demo software in Turbo Pascal and Basic.
Amplicon Liveline Ltd. Tel., 0800 525 358; fax, 0800 525 3165 046.

Scorpion K4 K4 is a MicroRobotics product and 4byte of data memory, in addition to external expansion facilities. Unique to this board is the boot rom, which inclines its independence from a host. Output dynamic range is over 95dB.
Sample Rate Systems Oy, Tel., 010 358 31 3165 045; fax, 010 358 31 3165 046.

PCMCIA adaptors. CARDport is a range of PCMCIA adaptors for users of laptops, notebooks and desktop computers not provided with a PCMCIA socket. Three models are available: CARDport eX, which is a portable card adaptor with its own rechargeable battery, connecting to the parallel printer port of any PC and accepting memory and disk drive cards; CARDport aS goes in the ISA expansion bus, an additional module fitting in a disk drive bay, to provide two sockets for any PCMCIA cards; and CARDport ide is a low-cost desktop PC adaptor for micro hard disk drives. All are supplied with software.
Chase Advanced Technologies, Tel., 0274 841316; fax, 0274 841502.

Audio digital signal-processing board operating independently of any host computer, needing only an unregulated supply and a case. It is based on the Motorola 56004 signal processing chip, has stereo analogue input and an 18 or 20-bit analogue-to-digital converter and an 18-bit output digital-to-analogue converter, which is followed by a programmable gain control. The module accommodates up to 32bit of program memory and 4MByte of data memory.
Amplicon Liveline is a programmable product, two g-p expansion interfaces. There are also two channels of serial i/o and four outputs, if required. A lower-power version for laptops is available, both types coming with demo software in Turbo Pascal and Basic.
Amplicon Liveline Ltd. Tel., 0800 525 358; fax, 0800 525 3165 046; fax, 010 358 31 3165 045; fax, 010 358 31 3165 046.
**Data communications**

HDSL transceiver. Brooktree announces the Bt8952 single-chip high-bit-rate digital subscriber line transceiver, claimed to be the first all-digital equaliser chip for HDSL technology for upgrading standard twisted-pair telephone lines to take higher bit rates for fast digital services. Brooktree's 88592 interfaces the 8952 to T1/E1 framers to provide a complete solution. The transceiver incorporates adaptive echo cancellation and also equalisation to compensate for phase and amplitude distortion caused by boosting the bandwidth of low-frequency copper wires. Brooktree Ltd., 0844 261969; fax, 261906.

**Notebook data acquisition.** Using a 165-pin connector or four dual in line controller, Keeley's DaPac is a portable data acquisition system which avoids the restrictions of the parallel port or PCMCIA slot. The unit runs all software written for the PC without modification. It is the same size as the compact 8/16 and can be configured for the application by selecting the acquisition board from a wide range, such as buffers being possible for high count levels or more interfaces. DaPac has its own power system working from AC mains. Keeley Instruments Ltd. Tel., 0734 576666; fax, 0734 596469.

**OEM modem.** Socket Modern 136 by TDC supports fax, voice and data, providing a BART-approved method of providing connectivity to PSTN and cellular networks. It can be fitted with a range of component options to allow configurations for 9600 bps data, 9600 bps fax send and receive and voice, supporting V.22bis, V.22, V.23 and V.21, plus V.42bis and MNP-5 data compression and error correction. Mobile systems are supported with MNP-10 protocol for cellular and satellites. ADCM compression is used for voice data. Telecom Design Communications Ltd. Tel., 0256 332800; fax, 0256 332910.

**Data acquisition box.** A compact, lightweight, external data acquisition box by National, the DAQPad-1200 is compatible with the parallel printer port of a PC and includes an AD converter or a 8-12 hour rechargeable battery pack. It has a 12-bit A-D converter accepting signals from eight single-ended or four differential inputs at up to 83.3ksamples/s, with programmable gain of 1-100, a 12-bit sample f/s A-D buffer, two 12-bit D-A converters, 24 lines of TTL-compatible digital I/O and three 16-bit counter/timer channels accessible by the user. The box is 242 x 82 x 57.5 by 5.9 National Instruments. Tel., 0635 523545; fax, 0635 523154.

**Development and evaluation**

**78K0 starter kit.** NEC's distributor, Sunrise Electronics, has a low-cost starter kit for the 78K0 family of 8-bit microcontrollers which includes a board with a shrink-clamp-programmer software, OTP programmer, cable and documentation. Assembler and debugger software provide full-screen interactive interface and single-step, and multiple breakpoints. Program loading via an RS232C interface to either terminal or PC, the program being downloaded and started under monitor control. The TLP790410WV has 32kbyte of ROM, 1056byte of RAM, 35 I/O ports, 16-bit and 8-bit counter timers, clock and watchdog timers, and two channels of serial interface, one of which being used, if required, as an I2C bus interface. Sunrise Electronics Ltd. Tel. 0908 263999; fax, 0908 263003.

**A different ICE.** To avoid the problems associated with using many microprocessor derivatives and, therefore, an increasing number of software libraries in the common base, Hitex has a new method of emulation in which the processor stays where it is, soldered in if required, and is interfaced to the emulator by a standard interface adapter, the ICE/Connect, which is supplied with a subset of the processor's signals. The adapter is identical for all derivatives of a processor family. Tel. (UK) Ltd., 0203 692066; fax, 0203 692113.

**£300 16-bit development.** At a much lower cost than that of in-circuit emulation, The RCS DB16 Designer's Board forms a complete development kit for Hitex microcontrollers. It consists of the board, Hitex's cross assembler, communications package and debug monitor, power supply cable, example programs in source code and documentation. The user needs only a PC with text editor. RCS Microsystems Ltd. Tel., 081 979 2004; fax, 081 979 6910.

**Computer peripherals**

**Solid-state disk.** AMC has a hard disk on a PC card, having cold-boot and full disk emulation. The PC Flash Drive is based on flash memory and the Flash File System to provide system memory at lower cost. It provides 32Mbyte capacity on one board, is mounted in a plug-in module and needs no bootstrapping, plugging into an ISA bus to replace both the disk and disk controller with its built-in software, and is compatible with dos and Windows and works on 8-bit and 16-bit ISA/ESATA buses and will operate as drive D; when other drives are being handled in both hex and binary formats. Innovate Ltd. Tel., 0604 661000; fax, 0604 660021.

**Forth 5 cross-compiler.** MPE's PC-hosted Forth 5 cross-compilers generates code for a wide range of target processors, offering interactive development, high compilation speed and online help to speed development of embedded software. Target code supplied includes a multi-tasker with message passing and event handlers, high-level interrupter and drivers. Microprocessor Engineering Ltd. Tel., 0733 339691; fax, 0733 631441.

**Real-time data analysis for Windows.** Hydra-Digs from SciTech is a Windows 3-based, multiprocessor data acquisition and control system, hard disk data capture, the interactive analysis and display and results documentation. A measurement and analysis process is designed on screen graphically, using a mouse to connect function blocks from a library, users adding their own functions or C-code routines where necessary. The translator to C code is generated by the software, the PC being freed for interface functions. Included is one card providing 16 analogue inputs, two analogue outputs, 16 digital inputs and outputs, a trigger input and a T805 25MHz transfer. The basic system will perform a 1024-point FFT at floating-point precision at a 5kHz real-time rate. SciTech. Tel., 0734 758587; fax, 0734 758748.

**Multimedia chips.** Mwave is IBM's solution for expanding the PC's area of activity to encompass multimedia. It is based on the company's IBM386/WX500 digital signal processing chip and allows the software implementation of all the expansion functions for a PC or workstation, including stereo sound, speech recognition, fax, modems and telephony. All is performed by a single chip. Blue Micro, IBM's British OEM representative, can supply evaluation boards in standard PC AT expansion card format, a range of software modules for basic functions already existing in existence. Intermetrics has a complete developer's toolkit, Mwave for Windows, and IBM has licensed Sound Blaster compatibility from Creative Technology, so that Mwave will be compatible with existing audio and multimedia applications. It is already compatible with CD-rom technology and the MPC standards. Mwave is also available to incorporate at chip level, with support available from Blue Micro. Blue Micro Electronics. Tel., 0604 603310; fax, 0604 603320.

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**Computer voice control**

Talk... is a computer system by Responsive Systems that listens to a voice and does interpret the text on screen, no intervention of the keyboard being needed. It uses Dragon Dictate and IBM Voice Type 2. A built-in tutorial allows the system to learn one's unique speech patterns, three vocabularies, 0, 5000 and 7000 words, being available in different versions. The package includes IBM's latest voice dictionary, although Talk... can be used with any desktop computer, hardware including IBM's mice designed to pick up very little ambient noise, 2000 users adding in addition to the vocabulary a 100,000-word dictionary for spell check, vg, adaptive learning to accommodate regional accents and speech impairments, and multiple user voice models for system sharing. It works with all dos applications such as Wordperfect, Wordstar, Word, Lotus 123 and Quickon, options including Windows voice control and Voice Tools to allow the development of specialist voice-driven applications.

Punctuation and formatting commands can be spoken or input from the keyboard, speed of test creation being around 30-40 words per minute; blocks of text can be input by a single spoken word. The whole process is faster than handwriting and faster than some typists. This type of voice response may be added to any 386 or 486 computer provided that it has at least 1MB of ram, the cost being £1999 for a 5000 word version. Complete systems start at £2899 in the 486/5000 word form. The system is scalable and can therefore be upgraded.

Responsive Systems. Tel., 051 662 4107; fax, 071 603 2109.
**LETTERS**

**From Douglas Self - Amplified defence...**

I thank Ben Duncan for his kind comments on my investigations into amplifier distortion (EW + WW, May 1994). But I also note with genuine sadness that his letter attempts to underpin a raft of unsupported assertions.

While I would happily slug it out line-by-line on every dubious statement, I doubt if The Editor would stand for it [No Ed]. So I will once more confine myself to power-supply rejection and “thermal distortion”.

I don’t know what Ben means by “economic with the facts”. There were eight articles full of them. His plaintive cry of “where are those measurements?” is a bit rich in view of his propensity to complain without ever offering any hard facts to support his views.

Where Ben got the idea that I rejected hi-fi regulators without trying them I do not know. I tried several versions of linear regulators in the 1970s - I still have one in the cellar – in the innocent belief that this was a good way to reduce hum injection. But I was dead wrong. They are complicated, expensive, difficult to design for HF stability under all conditions, and generally a pain to use. It may be that Ben has some insights that I lack. If so, I am truly cut off. But unless he is more forthright with information, it looks as if we shall never know.

Admittedly the generic amplifier I concentrated on is only one topology. But it is the basic structure of 98% of power amplifiers, and is surely a reasonable place to start. I do feel that I have shown that first-class hi-fi thd figures are obtainable with a simple unregulated supply - using reservoirs no larger than 10,000µF. I assure Ben that this also holds true for 4 and 2Ω loads, with or without various amounts of parallel capacitance up to 2µF.

Perhaps the topology that Ben prefers, but refuses to disclose, cannot emulate this performance. If so it seems like a good reason not to use it, because he has so far failed to specify any countering advantages.

All we have to go on are the nuggets of data published in his article (PSU regulation boots audio performance, pp. 818-822, EW + WW, October 1992) which I reproduce below:

<table>
<thead>
<tr>
<th>PSR with unreg psu</th>
<th>THD with unreg psu</th>
<th>THD with regulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>10Hz</td>
<td>-24dB</td>
<td>&lt;0.002%</td>
</tr>
<tr>
<td>1kHz</td>
<td>-57.6dB</td>
<td>&lt;0.006%</td>
</tr>
<tr>
<td>20kHz</td>
<td>not stated</td>
<td>0.04%</td>
</tr>
</tbody>
</table>

On the defensive

“For years industry has been crippled by the imperative for military development... Billions of pounds destined for the military have distorted the UK electronics industry grossly... The electronics industry must be led by marketing departments, not politicians...”

Frank Ogden, Comment, EW + WW, June 1990.

“Much of the relative prosperity in the UK can be traced back ultimately to our defence manufacturing activities... Arms, petrochemicals, nuclear technology... are what separate us from a rural peasant economy”.

Frank Ogden, Comment, EW + WW, April 1994.

Frank Ogden and Frank Ogden - are they by any chance related? Hypocrisy or MP bashing?

Richard Greatorex

London

Like it or not, the UK technology and electronics industry is still geared to defence interests and anyone who denies this would be very foolish. I don’t welcome the situation, and I shall work to change it. However, I am not so much of an idealist as to ignore the money which it generates. Neither should our politicians through political expediency.

Frank Ogden

Brass monkeys

Thank you for Help with hypocrisy (Comment, April 1994).

As a professional observer and amateur practitioner for more than 50 years I have been horrified at the iniquity of the top brass in British Industry and in particular the electronics, aerospace and automotive fields. GEC is certainly an outstanding example.

H Archer Watford

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ampilifier circuitry, around the nauseating CMRR trimmer appears faced to remain shrouded in secrecy - a sort of *Trimmer Celeste*.

Mead has simply come back with more of the usual unfounded, unattributable claims. He says that 'research has shown...' but what research? When was it done? Where can I read it? He has data that correlates his own audio priorities with sales figures, but can we not share some of this important information? If not, why not? And how would we go about getting it in his letter turn into 'professional listeners' two lines further on?

Mead says one of his prime concerns is to correlate what he hears with measurement, and the implication of his first letter was that he wasn't making a lot of headway, though I hope he will forgive me if this is a misinterpretation. To say it one more time, there is a huge body of psychoacoustical knowledge already available for study, though I get the distinct impression this is of vanishingly small interest to subjectiveists; a most strange state of affairs.

I fully sympathise with and share Alan Thomas' weariness with this debate (it's +111, March). He was right in his turn was resolved a long time ago, initially by a series of listening tests commissioned by Quad and carried out by James Moir in 1978. Three radically different amplifier technologies (valve, conventional BJT, and current dumping) were subjected to blind testing and proper statistical analysis. The result was unequivocal: the amplifiers could not be distinguished by listening to them. Since then various other tests have produced similar results, and those that have not have proved to be fatally flawed as regards the statistical design of the experiment. It is in the light of these results that engineers feel little enthusiasm for repeating experiments that require a great deal of care and effort if they are to be of any use at all, and which can only confirm existing knowledge.

I'm sorry if Mead finds it so grim to have attention drawn to the fatal inadequacies of his experimental technique, but then EMA + WWW is hardly the only arena for those seeking uncriticised adulation.

Whatever personal limitations Mead may choose to accuse me of - I assume he is trying to imply I have hearing difficulties, which is not very nice - he may rest assured that I shall continue to take an active interest in the phenomenon of uncontrolled listening tests.

Douglast Self

Forest Gate

London

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**Ins and outs of amplifiers**

Douglas Self's eight part amplifier series was an informative read. It brought back memories of my investigative audio experimentation twenty years ago and asked some of the same ideas.

Amplifiers have two external audio inputs: nominal signal input; and the loudspeaker output via the nfb (negative feedback) loop connection. Suppose we connect one end of an 4Ω resistor to the live output terminal of an amplifier and drive the other with as little as 1mVrms with respect to output ground. To maintain zero output potential, the amplifier then automatically sinks an extra 350mA in each half of its push-pull output stage.

In class A, device currents change equally but oppositely, smoothly and fractionally, so there is little nfb loop disturbance. In class B, virtually all current is derived from nfb-enabled open loop gain. The output stages are thus driven through both device non-linearities, inducing negative feedback modulation at frequencies two and four times that of the applied signal, respectively.

Composite loudspeaker have two or more driver resonances, with enclosures, crossovers and leads varying in character and sensitivity. In class B design, these in turn intermediate any medium- and high-frequency audio components riding on large amplitude low notes. It follows that higher levels of class B output increase the audible confusion while apparently improving dummy loud measurement figures. This could be the real reason why class A designs are subjectively pleasing, and we may need to reappraise testing techniques: what about measuring output stage distortion when it itself is driven and swept through 10Hz-5kHz by a reference power amplifier through complex impedances or real life loudspeakers? Or we could quiet tests with both input and output driven - independently but synchronously.

Moving to another subject area, 20W of audio is weak by today's standards, but in class A it generates +55V of heat. Scale upwards to produce a decent ×210W stereo amplifier and you have a small room heater.

Back in 2/305 days, I had encouraging results with a sliding bias class A 100W rms design that quiesced with 'reasonable' dissipation. There is now an opening to try this idea with Self's (Fig. 7) blameless design: I suggest the very simple circuit shown. Note that with sliding A the output bias increases linearly with 1000V, differing to different other current and other classes, including AB and sustained current B. The values shown in the circuit are estimates only. The 6.6kHz value should be carefully chosen according to power/impedance derivatives. C1 should be as small as possible consistent with sufficient hi, stability, and Vref set approximately four tenths of nominal. Induced current changes occur smoothly after voltage amplification stages and all is enclosed by the nfb loop for uncorrupted distortion figures should hardly increase. Standing currents are adequate to cope with real-life loudspeaker reactances and the output should still sound like good class A. Tiny feet, now big, saw off my audio work and I'm unable to try this idea. But if someone could do the soldering and plugging I'd be pleased to read their findings in this column.

Graham Maynard

Newtownabbey

N Ireland

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**Quiescent and controlled**

In the last part of his series on distortion in audio power amplifiers (EWW + WW, March 1994) Douglas Self suggests that it is not possible to control the quiescent current in class (A) amplifiers by using an extra negative feedback loop. But I must disagree. It can be controlled with a special kind of common-mode loop containing a non-linear network (1, 2). Using this technique, the quiescent current can be made independent of the temperature of output transistors, and a smooth transition from one side of the output stage to the other can be realised with ease. The output transistors can be made to operate in a non-switching manner - although some parts of the non-linear feedback network will usually be cut off (near) completely: when the output current is large, the non-linear network does not switch.

Besides, with this method, common-source or common-emitter stages can be biased in class AB. Unlike Mr Self, I use the term class AB whenever the quiescent current is large compared with the junction leakage current, but smaller than one half of the peak output current. Hence the output stage does not need to be of any sort of complementary voltage follower. Operational amplifiers using these class AB control loops have been described (3, 4) as a class AB power amplifier with a class AB control loop.

Marcel van de Gevel

Hautlenn

The Netherlands

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**References**


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**Power amp comments**

I have been following with interest Douglas Self's series on audio power amp design. On thermal runaway in Class A amplifiers, Self controls these by tight control of the quiescent current. The resulting intrusion of the stabilising circuitry into the amplifier circuitry seems to me to be inexplicable. Given that Class A does not need to be precisely controlled, I would like to call attention to a couple of other methods.

First, constant power output PSU. If memory serves me correctly, Linsley Hood's 'Simple Class A amplifier' (KW, April 1969) used a PSU whose power output was essentially constant over times longer than a second or two, short-term peaks being supplied from the reservoir capacitors following the regulator's. The amplifier normally consumes slightly less power than the PSU's maximum output. Should the amplifier move into thermal runaway, the system stalls like an overloaded get-set and the output...
LETTERS

Cables for hi-fi equipment

There is a grain of truth in some of Graham Nalty's statements (Complex cables defy physics, EW + WW, January) but the question is - how big a grain?

The veracity of any two statements does not mean one is contingent on the other. The door is green, the table is brown are both true, but the greenness of the door need not be anything to do with the brownness of the table.

The supercable suppliers and manufacturers are very good at selecting a diverse, convenient range of technical and scientific truths and implying that they are consistent. If Nalty would qualify his assertions (and thereby propose a theory to explain his perception of an improved performance) then it might be possible to assess their validity.

For example, if, as he claims, silver (or silver coated) conductors make the system perform better then it must be because such conductors improve the signal in some way. The premise here, of course, is that if silver is better, then copper is worse; implying that copper in some way degrades the signal. If not, then they both degrade, but the silver less than the copper.

It would be helpful if Nalty would explain in quantitative terms how this occurs.

D. R Yorke and BC Blake-Coleman
Southampton and Salisbury

Tack to basics

Douglas Sel (EW + WW, January), while preferring proper audio measurements to improper listening tests, leaves out that the former are subject to restrictions inherent in Fourier’s theory.

Theories are, after all, only convenient fictions to describe complex physical behaviour. To perform a mathematical approximation of this complexity, theories are based on some selected simplifying presumptions.

In the audio field, for example, a theory built on well chosen assumptions would yield measurements in line with reality, so those with golden ears would agree with the engineers.

However, these well chosen assumptions will, apparently, have to come from thinking outside Fourier, considering that conventional reasoning merely resulted in 40 years of fruitless feuding across a gap between hearing and engineering. To try and bridge that gap, science could perhaps reveal how to compute Fourier’s relevance to reality - maybe rated as percentage FRTR for common audio, radio and television, as well as for audio in discos and railways.

Trying to close the gap means research with supply rails centred on IV and a C-coupled output to avoid placing the output coupling capacitors in the signal path. The logic behind this is obvious. Since the PSU rectifiers only conduct on the peak of each half cycle, for most of the time the amplifier output current is flowing through the PSU reservoir capacitors. If these are not a problem, what is so terrible about the speaker output coupling capacitors if it simply that it is more obviously in the output signal path than the reservoir capacitors? The AC-coupled approach has two advantages: PSU circuit complexity is halved, and it is no longer necessary to ensure that the quiescent output voltage is precisely IV.

Chris Bulman
Milton Keynes

Unstable conclusions

What is the universe and how did it come about? When we see a stationary object we think of it as stable but it is not. The only way it can exist is to be in chaos. If it were stable it would have no energy and would not exist.

There was no ‘before’ the Big bang, because ‘no energy’ equals ‘no time’ and only chaos can exist. At the instant of the beginning only energy was produced.

We are told the big bang lasted only a billionth of a second, it may have taken a billion years because time was at its peak. Energy is still being produced, though only a fraction of that at the beginning, and time is still fixing it into what we perceive as matter. The chaos of the universe is what has slowed new energy to virtually nil.

What the universe consists of today is exactly the same as when it did not exist. ‘Nothing’ time and energy have there equal and opposite rather than an equation that equates to zero. We exist but equal nothing.

The speed of light is treated as a constant but it is energy and has no time in what time frame should it be measured?: big bang time or EW + WW, letters time.

J Hancock
Bournemouth

It's life... but not as we know it

Virtual reality is the current electronics hot issue. Now, by putting together several new technologies, we are probably as near as we will ever get to a Star Trek transporter.

The basic device would consist of a transmitter and receiver that can be plugged into a telephone socket. The receiver will be a virtual reality helmet with stereo headphones and two video displays. It will be connected to a box that decodes the video and audio data from the fractal compression system used to send it down the telephone system.

The transmitter will be a head-size object with binaural microphones and a pair of television cameras, and data will be fed via a fractal compression unit to the telephone line.

Next stage would be to mount the ‘head’ on a small airship-type flying machine, and set its computer to keep it at head height. Then directional signals could also be sent to it from the receiving person.

Unfortunately, people would not be able to use this product to visit each other, as the person receiving the visit would still see the ‘animated dustbin’ or whatever the transmitter looked like where their
friend was supposed to be. But a simple trick could be used to get over this. The person being visited could also wear a virtual reality helmet. It would display his home image, but instead of the animated dustbin it would display the image of the person making the visit, recorded by camera at the receiver end. Editing out the VR helmets would not be impossible, so each person would see the other as if they were a real person.

John de Rivaz
Cornwall

Engineers see sense?
I was interested to read the letter by John R Owen (EW + WW, April 1994). At long last, engineers are beginning to understand the subjective effect of physical phenomena on the sense organs. In the past we have described neural networks purely in terms of circuits and signals. Living biological cells are different, especially in vision, where artificial systems do not appear to have any subjective experience of the images that they see. Artificial vision is but a mathematical and analytical abstraction of biological vision. That is probably why, after forty years, researchers still ask why it is so difficult to get computers to do the simple things we humans take for granted?

In Machine vision for people, (Update, EW + WW, April) reporting on work being done at MIT, you mentioned the vital problem of the biological neural cell and electronics microchip interface. In the same issue, Research Notes reported how professor Warwick’s robotics research was shedding light on the differences between animate and artificial robot systems.

Finally, the never-ending saga on audio reproduction quality and perception reminds us of the subjective nature of our senses. There might never be a machine that will experience pleasure as we living entities do. Perhaps the Bible may yet prove to be the ultimate authority on these matters.

Thomas McInnes
Glasgow

PC paranoia
Jason Ross (Letters, April 1994) has misunderstood the views I attempted to express in a previous letter (December 1993). My aim was to question the motivation of the electronics and computer press in excluding machines not using a Microsoft operating system. They also ignore the fact that Windows is so poor in comparison with, for example, Acorn OS.

Many of arguments used to justify the ‘PC only’ policy are spurious. Reviewing an Acorn A3020 machine one expert commented: “…it only has 2Mbytes of ram and a floppy disc, I use a PC with 4Mbyte and a 225Mbyte hard drive”. Bally for him! But perhaps he should have been asking why it takes so much extra hardware to get from Windows anything like the same level of functionality given by Risc OS on the Acorn.

Another recently received schools to replace their BBCs with PCs. One reason was that: “…high flyers will need to know how to install Windows applications”, demonstrating the fact that he assumed schools were still limited to 32K-byte machines designed in 1981, surely the reason is why it should be so difficult a task. Working under Risc OS, which many schools will be running on Acorn machines, the task is trivial. Why not under Windows?

Most personal computers probably run no more than two or three programs regularly. So if you are never going to need them, what does it matter that there are several times more programs available for the PC than for the Acorn? Many teachers are now familiar with Windows and the Mac. Several new people merely involves raising a new directory, copying the initiating batch file with a new name and editing the directory name.

Two tips are to change the PROMPT when in the project directory and restore the standard PROMPT when QUITing. Also, if using for programming, arrange your edit batch file (E BAT) to assemble the program automatically when editing is completed. It sounds complicated, but it only needs to be done once. Setting up a new project merely involves raising a new directory, copying the initiating batch file with a new name and editing the directory name. Finally, a gui (graphical user interface) is not a panacea. Inevitably there will be problems, however standardised the applications interfaces under Windows or the Mac. My feeling is that three quarters of these will not be solved by introduction of a gui.

For example, I am very pleased with the ability of my recently purchased Windows or Mac to make use of Times proportional font in my HP Deskjet printer. It can do footnotes and endnotes and can print in two columns. But I cannot get the footnotes and endnotes to fit in columns. (Any advice would be greatly appreciated.)

David Noble
Essex

Bose and bouquets
Several readers have pointed out that in my article Using momentum to dethrone Einstein (EW + WW, Sept 93) I failed to mention the important work of Indian physicist Satyendra Bose, which provided a firm mathematical basis for quantum theory. Although Planck described the radiation of energy in terms of quanta, he did not regard light as actually consisting of packets of energy. For him, the concept was only a mathematical device, one which could explain the interaction between light and matter.

The Indian physicist Meghnad Saha thought that photons were more like particles than waves, and he was able to explain radiation pressure in terms of light quantum. Bose, working in obscurity in East Bengal, was quite unknown. In 1923, he attempted a mathematical derivation of Planck’s law of black body radiation. He succeeded only when he treated photons as though they were particles. His paper on the subject makes not even a mention of either waves or electromagnetism.

To derive Planck’s formula, Bose had to employ a new kind of statistics. Uncertain of its validity, he sent his paper to Einstein, who recognised its implications, translated it into German, and had it published in the journal Zeitschrift fur Physik. Einstein sent a copy of Bose’s paper to Erwin Schrödinger, together with Louis de Broglie’s famous paper which predicted that electrons can behave either as waves or as particles.

In a letter to Einstein, Schrödinger frankly admitted that it was Bose’s paper that made him realise the importance of de Broglie’s prediction.

The years that followed saw the development of quantum theory. But Bose took no further part in it. He returned to a subject nearer to his heart — the teaching and popularising of science. Just before his death in 1934, he described himself, rather sadly, as a comet which came once and never returned again.

John Ferguson
Surrey
Capacitance ratio meter

With only two ICs and without the need for a regulated supply or a crystal clock, this arrangement measures the capacitance ratio between two components to within 0.3%, presenting the reading digitally.

A latch-up-free astable flip-flop, made up of the four gates $G_{1-4}$, produces complementary square waves, the on times of which are independently determined by $C_1$ and $C_{ref}$. At switch-on, the two capacitors are at zero and $QA$ and $QA'$ are both 1, the second flip-flop accepting this input condition and toggling one way or the other indeterminately. Assuming that $QB$ is 0 and $QB'$ is 1, $QB$, charges $C_{ref}$ to the supply voltage by way of $D_1$, $G_1$ and $G_2$ inputs are now 1 and 0 respectively and the outputs become $QA$ and $QB'$ = 0, $QA$ and $QB$ = 1. $C_x$ now charges and $C_{ref}$ discharges via $R_1$, this voltage toggling the flip-flop when it reaches the threshold of set $A$. The new state discharges $C_x$ and the cycle repeats.

The ICL7107 3.5-digit A-to-D converter now indicates the ratio of integrated average voltages at the high and low inputs, its "thousands" decimal point being turned on. A potentiometer on the reference input is set so that the display shows a reciprocal reading when the capacitors are interchanged.

M S Nagaraj
ISRO Satellite Centre
Bangalore
India

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A simple way to high-pass and band-pass filters

Using only a low-pass filter consisting of an R and a C, this circuit will function as an active high-pass filter and, with the addition of a similar circuit with other values, a band-pass filter.

Inputs to the AD620 instrumentation amplifier are direct and via the RC low-pass section. At low frequencies, both inputs see the same signal, since the RC filter passes the signal and there is a common-mode input to the amplifier. Higher frequencies are attenuated by the filter and the amplifier receives the difference, which is amplified.

Effectively, the output of the circuit is the amplified output of the derivative of the RC section:

\[ \frac{v_2}{v_1} = A \left( \frac{1}{1 + \frac{RC}{\tau}} \right) \]

where \( \tau = RC \) and \( s \) is the complex frequency variable.

A band-pass filter can be made by inserting another RC section, preferably in the common input before the original filter.

The circuit has found application in the amplification of a small, higher frequency signal superimposed on a slowly changing one.

Jaroslav Chum
Geophysical Institute
Prague, Czech Republic

Binary-to-BCD converter

Converting an eight-bit binary input to binary-coded decimal can, on occasion, be useful in showing the output of an analogue-to-digital converter in decimal form.

In essence, the circuit clocks binary and BCD counters together until the output from the binary counter equals the input from the binary A-to-D converter, only the BCD output being indicated.

A 355-based clock at 7.3kHz drives both sets of counters to a maximum of 99 counts or until equality between the inputs from the A-to-D converter and the binary counter is detected by the 684 comparator. At this point, the comparator triggers a monostable flip-flop, which latches the BCD counter output so that the count is displayed. After a short delay, the same signal resets the counters, which remain reset and the count displayed for about 1s until the monostable pulse finishes, when the process recycles. Very little flicker is evident, since the process is fast.

To avoid the circuit cycling when the count is correct, a second latch between the binary counter and the comparator, so that a constant equality signal from the comparator and monostable ensure that the display only updates when the input from the A-to-D converter changes.

Richard Maggs
Rhiwbina
Cardiff

Special-purpose 74-series binary-to-BCD parts are a simpler solution for two digits but this circuit may prove more convenient as the number of digits increases – Ed.
Car radio loop aerial

This windscreen loop aerial is suitable for long and medium waves and VHF FM. An existing whip can be left in situ or an extra wire can be run parallel to one leg of the loop.

The 100nF capacitor, series inductance of $L_2$ and the loop tune the aerial to long wave, while medium waves are tuned by $L_4$ and the capacitance of the coaxial cable from the aerial to the radio. For VHF, the ring core $T_1$ has an outside diameter of 6.5mm and $T_2$ is the oscillator coil from a MW receiver, with the slug fully in. There is a performance improvement over a whip, particularly in tunnels.

D Di Mario
Milan
Italy

Windscreen loop aerial foils vandals and improves performance.

High-voltage, current limited power supply

This inexpensive supply was designed to test the breakdown voltage of components and high-voltage semiconductors, using switching techniques to supply current-limited outputs from 100V to 500V at low dissipation. The output voltage is unregulated, ramping up until the set current limit is reached.

Input is up to 500V of raw DC, any reservoir capacitor being removed and possibly reused as $C_{res}$ at the output. A switch at the input would allow the test voltage to be applied after connecting the device under test. Collector/emitter voltages of $T_{1,3}$ or $T_{1,2,4,4+}$ if the the extra devices to double the voltage rating are used, must withstand the input voltage but, since all the transistors are either on or off, dissipation is low and safe operating-area derating is unnecessary; TO-92, E-line or TO-126 packaged devices may be used. Collector-current ratings should be well above the current limit. The reservoir capacitor $C_{res}$ should have low equivalent series resistance, $R_{lim}$ being set to limit inrush current.

Amplifier $IC_{1B}$ reads the voltage drop caused by output current in $R_{sens}$, which can be varied in value to allow current limits other than 20mA. Although common-mode voltage is irrelevant in a floating supply, the input to the amplifier is attenuated to allow ground HT supplies, $IC_{1B}$'s ±10V CM limit coping with ±500V at the input if the $1MΩ$ resistors are properly rated.

Gain of the second amplifier sets the current limit and its 3MHz gain bandwidth product limits servo loop bandwidth and rate to around 15kHz at a gain of 200. Used as a comparator, the third amplifier controls the opto-couplers.

Ben Duncan
Lincoln

Windscreen loop aerial
High-voltage current limiter/stabiliser

The basic circuit shown in Fig.1 is a current limiter using a junction fet, which operates according to \( I_{\text{lim}} = \frac{V}{R_1} \). For higher power, the circuit of Fig. 2 is better, the mosfet being fitted with a heat sink. The mosfet holds off the supply voltage and \( R_2 \) is a current sensor, the voltage across it driving the bipolar transistor base to apply feedback around the circuit. A 10V zener provides a supply to \( R_2 \), and since it is connected to the top of \( R_2 \), takes into account the current in \( R_2 \).

As the circuit stands, the current limits at 100mA, with an output impedance of around 100kΩ and with a maximum applied voltage of about 175V although, since 1000V mosfets are available, the circuit can be scaled up.

Replacing the bipolar transistor with a programmable zener gives better stability and a higher output impedance of about 1MΩ, both the quoted impedances being estimated from the performance table shown.

CID Catto
Cambridge

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Filtering out design problems

Choice of a filter for rf power amplifiers must not only take account of intended applications, but also of the components available. Norm Dye and Helge Granberg explain the theory – and practice – of good filter design. From the book RF Transistors: principles and practical applications.

Filtering for output harmonic reduction is needed in virtually all solid state rf power amplifiers – especially those for radio communications. Specifications depend on the application, frequency of operation and power level.

Wide-band amplifiers have much higher harmonic content than narrow-band ones, the worst cases existing at the lowest frequencies. An amplifier with a bandwidth of 10-175MHz, for example, would not only pass the second harmonic up to 85-90MHz and the third harmonic up to about 60 MHz, but will amplify these frequencies along with the fundamental.

Harmonics generated at higher than these frequencies fall outside the amplifier's bandwidth. Their amplitudes will gradually diminish at increasing frequencies, at a rate depending on the amplifier's gain characteristics outside its intended pass band.

At 10MHz, the same amplifier would pass and amplify signals all the way up to the seventh even and fourth odd order harmonic. Viewing the fundamental waveform on an oscilloscope would show it to resemble a square wave more than a sine wave – which is normal considering the wide distribution of harmonics. In a single-ended amplifier, the second harmonic is the most troublesome. But in push-pull amplifiers, the even-order harmonics are suppressed. In one with a 4-5 octave bandwidth, the amplitude of the second harmonic can be 30-50dB below the fundamental, depending on the circuit balance, yet the third order harmonic may be attenuated only 10-12dB.

In narrow-band systems, band-pass filters can be used for rf power amplifier output harmonic filtering. But such filtering is almost exclusively done with low-pass filters.

Extending normalised tables

Normalised tables that help in designing low-pass filters – available in textbooks and other publications – can be used for designing high-pass, band-pass or low-pass varieties. Only a few simple calculations are necessary to derive the normalised values from the tables, and filters so designed can be computer analysed to verify their accuracy.

The technique is applicable up to frequencies where lumped constant elements cease to be practical. But at high uhf and microwave frequencies, microstrip techniques can be used to realise the components needed in the low-pass filter design. Chip capacitors can be used up to 800-1000MHz, but lumped inductors become ineffective above 500MHz.

When calculating lengths of line in microstrip to obtain distributed Ls and Cs, remember that microstrip is not a true...
transverse electric magnetic (TEM) mode of propagation. Velocity of propagation is reduced by the medium in a similar manner to that encountered in true TEM mode transmission lines such as coaxial cable and stripline, but, to lesser extent.

Velocity reduction, similar to wavelength reduction discussed previously (March, EW + WW), can be expressed as:

\[ v = \frac{v_0}{\sqrt{\varepsilon_r}} \]

where \( v_0 \) is the velocity of light in a vacuum \( (3 \times 10^8 \text{m/s}) \) and \( \varepsilon_r \) is the relative dielectric constant. The length \( l \) of a microstrip line for a specific inductance is:

\[ l = \frac{L_{\text{eff}}}{Z_0} \]

where \( L \) is inductance in nH, \( \varepsilon_{\text{eff}} \) is effective velocity in the medium given in the expression above, and \( Z_0 \) is the characteristic impedance of the line in ohms.

If we select the desired value of \( L \) to be 2.5 nH and use microstrip line made with alumina (\( \varepsilon_r = 10 \)) having a \( Z_0 \) of 100 \( \Omega \), then \( \varepsilon_{\text{eff}} \) = \( \sqrt{8.9} \) (Fig. 1) and \( \varepsilon_{\text{eff}} = 30/\sqrt{8.9} = 10.1 \text{ cm/μs} \). Substituting in the above formula: \( l = (2.5 \times 10^{-1})/10 = 2.5 \text{ cm} \).

A plot of inductance for different line impedances is shown in Fig. 2. For convenience, \( \varepsilon_{\text{eff}} \) normalised to \( \varepsilon_r \) is also plotted on the vertical axis. The graph clearly shows how the value of \( \varepsilon_{\text{eff}} \) approaches \( \varepsilon_r \) as line impedance approaches zero.

Note that in the above example, \( Z_0 = 100 \Omega \) and \( Z_{\text{in}} = 50 \Omega \), so the line impedance is not more than 10% of \( Z_{\text{in}} \), and \( Z_{\text{in}} \) can be assumed equal to \( \varepsilon_r \).

The industry standard characteristic impedance for RF power test systems and equipment is 50\( \Omega \), so all subsequent material

**Chebyshev or Butterworth?**

Two basic types of low pass filters are commonly used to suppress harmonics of the desired frequency in the RF output of solid state amplifiers: Chebyshev and Butterworth. Several variations of each include the elliptic function filter (also called the Cauer-parameter filter), the constant-K filter, and the m-derived filter.

Each has its own characteristics, performance, advantages and disadvantages. In addition filters can be divided into inductive input and capacitive input categories.

Most RF power applications make use of either a straight Chebyshev or one modified to provide the elliptic function characteristics - having a sharper cut-off, but lower far band attenuation, as shown below.

The modification also provides deep and sharp notches in the out-of-band attenuation. Some of these notches can be fine-tuned to the specific harmonic frequencies, improving out-of-band attenuation but decreasing return loss. The option is also only practical in fixed frequency or very narrow frequency range applications.
and data refer to this impedance unless otherwise noted.

Choosing a filter
Using only a plain Chebyshev or Butterworth filter to suppress harmonics of the desired frequency in the rf output of solid state amplifiers makes it difficult to obtain sufficient attenuation. This is especially so for the second harmonic, except with a well balanced push-pull circuit which provides even order harmonic suppression by itself; the push-pull configuration has a cancellation effect, as mentioned earlier.

Low pass filters have – in general – characteristics which attenuate unwanted harmonics by reflecting them back to the source. The effect is to alter the impedance for the harmonics, which was originally 50Ω without the filter.

Series-L input type low pass filters present a high impedance for the harmonics; with a shunt-C input type, the harmonics will see a high impedance for the harmonics; with a solid state amplifier, can be expected to have superior efficiency characteristics. On the other hand, the shunt-C input filter results in better linearity and harmonic suppression, though it can result in abnormally high rf currents in the line connecting the signal source to the filter.

In the shunt-C input filter, harmonics are directed to ground, so the amplifier will see a lower than optimum output load line – especially at the harmonic frequencies.

The filter’s effect is reduced when inductance is added between the amplifier output and filter input. Also, a transmission line will convert it to a series-L input type.

In a series-L input filter the harmonics are either dissipated in the series inductance of the filter or reflected back to the amplifier output, presenting a higher than normal load line to the amplifier.

Severity of the above characteristics for each filter depends on the initial harmonic content of the amplifier and on frequency of operation in the pass band of the filter. The exact conditions under load mismatch in each case depend on the phase angle of the mismatched load, in addition to phase delay of the filter.

One solution to avoid problems is to use a diplexer in the amplifier output.

The device is actually nothing but a dual set of filters, one low pass and one high pass. Their cut-off frequencies are designed so that the low pass filter passes only the fundamental frequency to the primary load. The high pass filter presents a high impedance to the fundamental, but passes the harmonics and ‘dumps’ them into a secondary load. The solution looks ideal, since 50Ω loads would be presented to both the fundamental frequency and the harmonics. The secondary load is only required to handle the power level of the harmonics, typically up to about 10% of the power level at the primary load.

Table 1. Component values for six filters covering the 1.6-30MHz spectrum. The normalised values, as well as the actual values of the low-pass filters, are shown in the lower part of the table. The upper part shows the specified numbers from which the normalised and actual values are derived.

<table>
<thead>
<tr>
<th></th>
<th>30MHz</th>
<th>21MHz</th>
<th>14MHz</th>
<th>7MHz</th>
<th>3.5MHz</th>
<th>1.6MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>fp (MHz)</td>
<td>32.0</td>
<td>23.0</td>
<td>14.5</td>
<td>7.5</td>
<td>4.0</td>
<td>2.10</td>
</tr>
<tr>
<td>lp (MHz)</td>
<td>48.0</td>
<td>34.0</td>
<td>20.0</td>
<td>10.0</td>
<td>5.6</td>
<td>3.20</td>
</tr>
<tr>
<td>Ls (Lpfp)</td>
<td>1.50</td>
<td>1.48</td>
<td>1.38</td>
<td>1.34</td>
<td>1.45</td>
<td>1.52</td>
</tr>
<tr>
<td>Ap (passband ripple)</td>
<td>0.044</td>
<td>0.044</td>
<td>0.044</td>
<td>0.044</td>
<td>0.044</td>
<td>0.044</td>
</tr>
<tr>
<td>Ap (dB)</td>
<td>-45</td>
<td>-45</td>
<td>-45</td>
<td>-45</td>
<td>-45</td>
<td>-45</td>
</tr>
<tr>
<td>Cref (pF)</td>
<td>100.0</td>
<td>140.0</td>
<td>220.0</td>
<td>420.0</td>
<td>760.0</td>
<td>1430.0</td>
</tr>
<tr>
<td>Lref (nH)</td>
<td>250.0</td>
<td>349.0</td>
<td>525.0</td>
<td>1050.0</td>
<td>1970.0</td>
<td>3650.0</td>
</tr>
</tbody>
</table>

Normalised values Actual values = CrefLref (pF) or Lref
Cref = 1.90 119.0 161.0 262.0 500.0 905.0 1700.0
Lref = 0.496 42.7 60.0 94.0 179.0 324.0 610.0
Cref = 1.312 131.2 184.0 288.0 551.0 997.0 1875.0
Lref = 0.232 23.2 32.5 51.0 97.5 177.0 332.0
Cref = 0.696 69.6 97.5 153.0 292.0 529.0 995.0
Lref = 0.899 225.0 314.0 472.0 944.0 1770.0 3280.0
Lref = 1.118 279.5 390.0 587.0 1174.0 2200.0 4080.0
Lref = 1.181 295.0 412.0 620.0 1240.0 2325.0 4310.0

But in spite of its advantages, the diplexer is practical only in single-frequency or extremely narrow spectrum applications, except for certain military equipment where space and economy are of less importance.

Design procedure
Design of low-pass filters using tables of normalised element values is relatively straightforward. All that is required is to set the specifications (Fig. 3):

1) Cut-off frequency fp (in MHz);
2) Stop-band frequency fs (in MHz);
3) Reference low-pass Wc = f/fs;
4) Required stop-band attenuation A (in dB) at frequency fs;
5) Allowable return loss RL (in dB) or voltage reflection coefficient I/1 (in %), which determines the band-pass ripple Ap (in dB);
6) Input and output impedances (Z).

Using the tables from several sources – a filter type can be selected and its degree (how many elements are required to satisfy the conditions specified) determined.

Sometimes the compromise necessary to reduce the number of elements and complexity of the filter may result in only a minor degradation in performance characteristics. Normally eight filters are required to cover the 1.6-30MHz rf frequency spectrum without gaps, even with sharp cut-off elliptic designs. But sometimes frequency bands such as the ham radio spectrum up to 30MHz (1.6, 3.5, 7.0, 14, 21, and 30MHz) can be covered with only six filters of the same type because continuous coverage is not required.

Putting theory into practice
Let us examine a low-pass filter design with fp = 32MHz and the lowest usable frequency of 24MHz, for example. Then fs would be 2 x 24, or 48MHz, resulting in 1/1 = fs/fs = 48/32 = 1.50. Ap is set at -45dB and the maximum allowable reflection coefficient I/1 at 10%.

For all the above reasons, a series-L input type filter seems to be the best choice. Two different configurations could be used: one designed with series-LC shunt elements; the other with shunt-LC series elements. Shunt LC is far more popular and is easier to implement in practice, since it uses fewer inductors. To make the filter a series-L input type, it must be an even degree, meaning that it must have an even number of elements.

Tables of normalised values for elliptic low-pass filters indicate that at least six elements are required for Ap = -45dB, I/1 = 10% and 1/1 = 1.50. If the reflection coefficient I/1 is converted into a decimal: 5/100 = 0.050, the mismatch loss or pass band ripple can be calculated as -10log(I1 - 0.05)/0.01 = 0.011dB. This – as well as the actual values – is theoretical, assuming an infinite Q for the elements. There will not be a large change if the loaded Q is 100. A Q of 20 however would result in a considerable loss in Ap and a 1.2dB decrease in Ap. The largest influence of the reduced Q can be noticed in the depth of the notches, which are not of primary importance.

Next we find the reference L and C values:

Lref = R/(2πfp) = 50/201 = 249nH
Cref = (1/RL)/2πfp = 0.020/201 = 99.5pF.

These values multiplied by the numbers from the normalised tables will give the actual L and C values required for the filter elements. So values of the actual elements of the six element L-input elliptic function low-
Composing values closer to the non-standards carrying capabilities to be increased, and the case at higher frequencies. Paralleling of \( 520 \) required in many instances is easier too. High allows inexpensive disc types to be used. 

multiple spectrum analyser - although this may not be abnormalities always recommended. But in this case no abnormalities were noticed when the responses were checked with a sweeper and a spectrum analyser - although this may not be the case at higher frequencies. Paralleling of multiple capacitors allows their current carrying capabilities to be increased, and allows inexpensive disc types to be used. Composing values closer to the non-standards required in many instances is easier too. High voltage (3000V) types were selected, since under certain load mismatch conditions they may be subjected to high rf voltages. Typically the rf voltage ratings of such capacitors are approximately 30-35% of their dc ratings.

Inductors should be located so that adjacent ones are at 90° angles to each other, minimising the possibility of mutual coupling. \( L_1 \) is an air-wound inductor and \( L_2 \) and \( L_3 \) are wound on phenolic, non-magnetic toroids for their more convenient shape factor. At lower frequencies (below 15MHz) all inductors can be toroidal to reduce their physical sizes. The toroid material permeabilities (\( \mu_r \)) should be 10 or less, limiting selection to powdered iron since the minimum \( \mu_r \) of ferrites is around 30.

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Relays can be relied on for filter switching at hf. (Figs. 5, 6 and 7) but they should be of a low contact inductance type such as Omron G2R or equivalent manufactured by Magnecraft and several other companies.

At higher frequencies, where excessive parasitic inductances become increasingly critical, pin diode switches are probably the only choice for a designer. Calculation of the rf voltages and currents in each element tell us the wire size required for the inductors and what the ratings for the capacitors should be.

For certain elements such as \( L_1, C_1 \) and \( C_3 \) (Fig. 4), manual calculation would be fairly straightforward. For the remainder, it would be complex, but programs now exist for the pc and Macintosh which optimise existing designs and plot the \( S_1, S_2, S_3, \) etc.

Other programs handle a more comprehensive design and calculate the nodal currents and voltages as well.

**Skin effect**

In the design example, \( C_2 \) and \( C_4 \) are exposed to the highest currents and \( C_3 \) is subjected to the highest rf voltage.

At a power level of 2000W, for example, the numbers are 11.2, 11.4A and 556V respectively. Since the skin-effect makes the current carrying capability of copper wire under rf conditions frequency-dependent, use as heavy gauge wire as practically possible to increase the conductor’s surface area.

In addition to heating effects, conductor size affects the inductor Q values.

Skin depth \( (d) \) of a copper conductor is approximately 0.009mm at 100MHz. Based on this reference, for practical purposes, the skin depth versus frequency is:

\[
d = 0.009 \times \sqrt{(100f)}
\]

where \( f \) is the actual frequency in MHz and 100 is the reference frequency in MHz. The resulting final numbers for 1.6 and 30MHz are 0.071mm and 0.016mm respectively. Usually five to six skin depths are considered adequate for good engineering practice, although rf current carrying capabilities diminish in the deeper layers.

Prompted by these numbers, experiments were conducted with inductor wire sizes of AWG #16 and #14, and no significant differences in performance or operation of the filter were noticed.

But for rf voltages in high power filter elements, the wire wound on ferrite or powdered iron toroids should be covered with some type of high temperature sleeving such as ptfe to prevent possible arcing to the core. High voltage, inexpensive disc capacitors suitable for high power filter applications up to 30-40MHz are available from several manufacturers.

The filter described here has been tested and operated, at length, a power level of 2kW. Common pc board construction techniques were used, with a ground plane on the component side, continuous except for clearances provided for feed-throughs (Fig. 6). The pc board material is G10 epoxy-fibreglass with a dielectric thickness of 1.6mm and 2oz copper on each side.

There were questions in the early design stages, over whether G10 dielectric material would have excessive losses at 30MHz, but this has not proven to be true.

At vhf (up to 200MHz) power levels of 2kW would be difficult to obtain without use.
of high quality components. Toroidal inductors as used in a hf design may be impractical and multi-layer ceramic capacitors such as ATC type 100E or Transistor type MPH are recommended.

At uhf, the high power filter design requires a completely different mechanical concept, such as etching or depositing the inductors and capacitors on a low loss substrate. Leadless chip capacitors would also be required to provide any degree of repeatability.

A single unit can always be 'tweaked in' to meet the specifications. But there may be a problem if the item has to be mass produced—especially with the inductors, which must definitely be air-wound or of stripline construction. As the frequency increases, the power handling capabilities of the components decrease exponentially due to higher losses and shallower skin depth of the conductors.

Filter switching with relays, feasible at hf with certain types, is not possible at higher frequencies because of the high series inductances of the relay contacts. In rf power applications at vhf and uhf, pin diode switches are about the only way to switch signals. But at higher power levels the number of diodes required per filter makes this technique costly.
Designing antennas for wireless networks

Wireless local-area networks generally use lower microwave and upper uhf, typically between $800\text{MHz}$ and $3\text{GHz}$ and often at $2.5\text{GHz}$. Antennas for such systems are the subject of application note AN143-1.3 from GEC Plessey, which provides both an explanation of the various types of antenna and two worked examples.

Antennas for wireless lans are installed on the equipment enclosure which is either rectangular or cylindrical. They are usually around one or two wavelengths in size. Since the enclosure is in the near field of the antenna it significantly affects performance. It is best to think of both the antenna and the enclosure as a composite radiating structure.

Gain is usually defined relative to an idealised isotropic antenna; an isotropic element would produce a gain of 0dB in all directions. Higher gain in one direction can only be achieved at the expense of reduced gain in another direction. The isotropic antenna is however unrealisable.

 Usually, an electrically small antenna produces a dipole-type polar diagram with nulls in two directions and omnidirectional in the plane normal to the null axis. In wireless-lan applications, it is desirable to have these nulls vertically upward and downwards, and the omnidirectional plane horizontal. Vertical monopoles or dipoles, or normal-mode helixes all have the appropriate characteristics.

Radiated energy from an antenna is polarised, usually either linearly or circularly. In linear polarisation the electric field vector lies in a defined direction normal to the direction of propagation. Circular polarisation involves an electric vector rotating around the propagation direction so as to lie always in the plane normal to that direction.

Most efficient power transfer is obtained when transmit and receive antenna polarisations are matched. In the extreme case of orthogonal polarisation, very little coupling, i.e. around $-8\text{dB}$, takes place between antennas. As a result, a vertical dipole and a horizontal dipole will not couple, while two vertical dipoles will.

Linear polarisation generally leads to simpler antennas; circular polarisation is produced by helixes or by phased feeding of a pair of linear antennas. This isolation between orthogonal antennas can be used to advantage in multiple access systems.

A poor match can also cause excessive reflected power in transmit mode which is returned to the transmitter with unfortunate consequences for the output devices. Low voltage-standing-wave ratio is relatively easy to achieve in wireless lans due to their narrow bandwidth.

Bandwidth should be qualified by defining

\begin{itemize}
  \item **Dipole**
  Dipole antennas are simple antennas with well-known characteristics. If there are particular space constraints, they can be configured in free form with modification to the radiation pattern. The dipole is linearly polarised and typically a half wavelength long. The best location is on top of equipment such as a cellular phone or walkie-talkie. It is possible to print the dipoles onto a dielectric substrate for internal mounting but performance is reduced.

  \begin{figure}
  \centering
  \includegraphics[width=0.5\textwidth]{dipole}
  \caption{Dipole}
  \end{figure}

  \begin{figure}
  \centering
  \includegraphics[width=0.5\textwidth]{monopole}
  \caption{Monopole}
  \end{figure}

  Closely related to the dipole is the monopole. It requires a ground plane or counterpoise, which may be the equipment enclosure. Mounted on top of equipment, a monopole will give a relatively clean radiation pattern, but will not generally be aesthetically acceptable. It does, however, provide a simple reference case for comparison with other antennas. Departures from the ideal monopole pattern are readily identified and attributed to the equipment enclosure. A monopole will be typically one quarter wavelength tall.

  \begin{figure}
  \centering
  \includegraphics[width=0.5\textwidth]{slot}
  \caption{Slot}
  \end{figure}

  Slot antennas are closely related to the dipole, and are very suited to integration into an equipment enclosure. However they need a ground plane, and often a backing cavity. This can lead to the antenna being relatively narrow band. The antenna can be driven from an unbalanced feed across the slot, the feed point being chosen to give an acceptable input impedance.

  \begin{figure}
  \centering
  \includegraphics[width=0.5\textwidth]{loop}
  \caption{Loop}
  \end{figure}

  The loop is a dual of the dipole, but usually requires more space. Its polarisation is complementary to that of a dipole.
\end{itemize}
the parameter being considered. An antenna may produce acceptable gain over a particular bandwidth, but its VSWR may only be acceptable over a much smaller frequency range. It is common however to talk of bandwidth as the frequency range over which all parameters of interest meet their specified values.

Bandwidth is often quoted as a percentage, and is obtained from the ratio of the highest frequency to the lowest. Bandwidths of 5% to 10% are common; an antenna with a bandwidth over 20% would be considered broadband while one with less than 2% would be narrow band. Special antenna designs are available with theoretically unlimited bandwidth, but they are physically large.

**Enclosure interaction**

Interaction between an antenna and objects near to it is particularly marked when the object is a few wavelengths in size. If the body is very small, say less than one wavelength, the total radiation pattern is usually dipole in form.

When the body is very large, say more than ten wavelengths, the antenna can usually be designed to be independent of the body by providing a ground plane. Between these limits, the body is not sufficiently large for a suitable ground plane to be incorporated, nor is it so small that the dipole pattern is obtained.

Interaction of the antenna with its surroundings needs to be considered. Scattering from nearby objects such as the equipment operator and desk top will affect the radiation pattern. Anechoic chambers should be used for antenna characterisation since they allow evaluation in a scattering-free environment.

**EMC**

Since an antenna is designed to provide electromagnetic coupling between free space and the interior of an equipment enclosure, there are EMC implications. As far as possible, the rf 'window' represented by the antenna should exclude out-of-band frequencies.

In addition, the antenna structure must not penetrate the EMC screening surrounding the equipment. These constraints can present a challenge to the antenna designer, who can only achieve acceptable antenna performance if the antenna is adequately separated from conductors and ground planes.

**Multipath**

Wireless lan antennas operate in a high multipath environment. This is combated to a degree by diversity working using two antennas spaced a quarter wavelength apart. Reflections from vertical and horizontal surfaces tend to preserve linear polarisation, while changing the handedness of polarisation. Linear polarisation is therefore preferable.

**Simple sleeve antenna**

A sleeve antenna can be made using tubing for one arm of a half wave dipole. Coaxial cable is passed through the tubing, and the centre conductor of the coaxial cable forms the other quarter wave arm of the dipole.

Screeing of the coaxial cable is trimmed back and connected to the top of the tubing. For best performance, lengths of the tubing and the projecting section of the inner conductor should be adjusted using a network analyser for minimum VSWR at 2.45GHz.

Tubing diameter is 4mm and the coaxial cable is 2mm outside diameter. An overall covering of heat-shrink tubing could be used to protect the antenna, with adjustments to the length of the dipole elements to allow for the consequent change in electrical length.

**Helix**

The helix antenna can be very compact. In general, helices have several radiating modes. These include axial mode, in which the helix radiates a circularly polarised wave along its axis, and normal mode, which is of particular interest in wireless lan applications. In normal mode, the helix radiates a linearly polarised wave with a maximum in the plane normal to the helix axis. The radiation pattern is identical to that of a monopole, but the helix is more compact than the corresponding monopole.

**±18bit a-to-d conversion at 60µA**

Resolving ±500mV inputs to 2µV, the MAX132 consumes only 60µA while operating or 1µA in sleep mode. No intermediate signal conditioning is needed: thermocouples, strain gauges, etc., plug directly into the analogue switch and are routed straight to the converter.

Serial interfacing reduces board space. It also simplifies remote data acquisition and makes isolation easier. To expand the number of channels, the ADC's four digital outputs can directly control a multiplexer or programmable gate array. This eliminates glue logic and additional serial control lines.

Inherent 50/60Hz rejection makes the converter suitable for industrial environments. Only brief details of how to apply the device are contained in Maxim's fifth Analog Design Guide but an evaluation kit is available.

**Applications**

Maxim Integrated Products, 20b Horseshoe Park, Pangbourne, Reading, RG8 7JW. Tel. 0734 845255, fax 62 7cm

This high-resolution low-noise analogue-to-digital converter has a 10µA input figure and interfaces directly to low-level output devices such as thermocouples and strain gauges.
**Solar-powered battery charger**

Remote instrumentation such as used for weather analysis often relies on solar power with battery back-up. Equipment being driven can consume considerable power in bursts while measurements are being made but very little averaged over relatively long standby periods.

Nickel-cadmium cells are ideal for this type of application provided that charging circuitry prevents overcharging and contributes negligible current leakage during hours of darkness. This circuit, from *Linear Technology Chronicle* Vol. 2, No 2, provides constant charge current over a wide range of light levels from a small solar panel. When solar-panel output falls to zero, the circuit automatically disconnects from the battery.

Power for the LT1073, configured as a boost converter, is provided by a 6V solar cell array. Current is monitored via the 13Ω resistor, which keeps charging constant at 16mA.

Unattended data gathering instruments often rely on solar power with battery back-up. Charging circuits require two features - low leakage in hours of darkness and overcharging protection.

**Fax machine design**

Circuit-function outlines for a high-performance fax machine are presented in Motorola’s *DC411* application note entitled *An MC68302-based fax machine*. Groups 2 and 3 are accommodated, while group 4 is an expansion capability.

Upgrading to group 4 involves using the MC68302 built-in ISDN channels and ISDN interface chips to replace the group-3 modem chip. Maximum communication speed is 14,400bit/s. The design supports error correction and integrated voice/fax facilities.

Although the note covers both hardware and software, it is intended as a design concept only. The functional block diagram and software chart shown here are the only illustrations presented. Since the note mentions specific devices for the various functions however, all that remains for the designer to do is collect the various data sheets, interface the chips and write the software - well almost.

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

**Elements of a high-performance fax machine for groups 2 and 3. Communication at up to 14,400bit/s is possible.**

Using integrating components such as the MC68302 at the heart of a fax machine reduces software complexity.

**Diagram:**

- **Solar-panel diagram:**
  - Solar panel
  - Battery
  - Charging circuit

- **FAX modem diagram:**
  - EIA-232 line driver
  - Printer
  - Scanner
  - SCC
  - TIMERS
  - MC68302
  - DATA BUS, IDMA, SCC, SCP
  - ROM
  - 8 or 16
  - 0.5 MBYTEs DRAM
  - ASC
  - ASIC
  - LCD display
  - Handset
  - Paper feed, printer & paper cut motors
  - A/D converter
  - Real-time clock + RAM
  - Line transceiver
  - Speaker
  - Keypad
  - Commands, call number
  - Top-level control
  - T.30 protocol
  - T.4 algorithms
  - LCD display driver
  - Printer driver
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  - RTC driver
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