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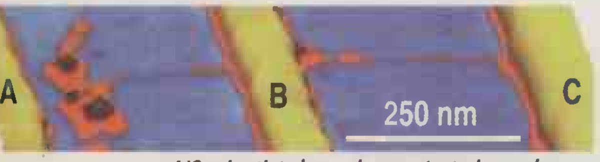
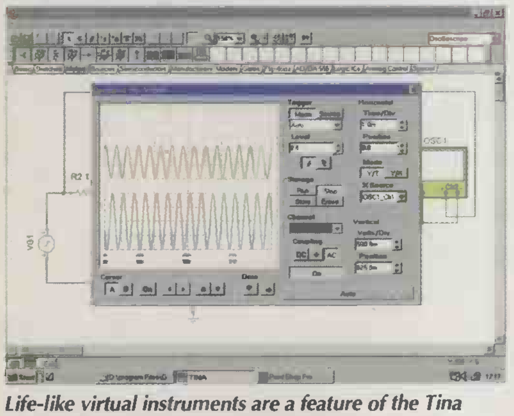


US scientists have demonstrated a carbon nanotube that behaves like a diode. For this and other news stories, turn to page 709.



Life-like virtual instruments are a feature of the Tina circuit simulation package reviewed on page 738.

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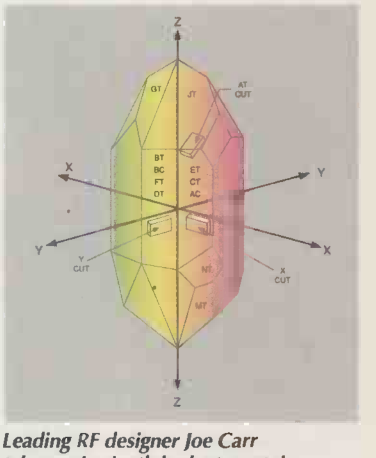
Cover Illustration Hashim Akib



Leading RF designer Joe Carr takes an in-depth look at crystal oscillators from the cut onwards, starting on page 780.

Semiconductor data galore: for more information on this month's cover mounted CDs, turn to page 728.

October issue on sale 9 September

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A wireless free for all

Radio waves are buzzing with talk of the latest regulatory proposals to come out of Brussels. Mobile communications and radio systems manufacturers in the UK and other European countries are being threatened with the prospect of a flood of substandard but cheap foreign products on to the market.

And those clever bureaucrats have decided in their wisdom that there is to be no mandatory product testing in the EU to protect suppliers and users from dodgy radio receivers and security devices.

National type approval requirements designed to ensure that all radio equipment sold in the UK works properly and is safe to use will be scrapped next year at the stroke of a pen in Brussels. In future, manufacturers will only be asked to take responsibility for the safety of their products. Approvals will not necessarily be backed up by mandatory product tests.

We know why the changes are being made. Self-assessment is fine if regulators want to cut their costs. But will it protect users from substandard products, imported by little known Far East suppliers who are less than rigorous in their self-assessment practices?

According to the Low Power Radio Association, the proposed Radio & Telecommunications Terminal Equipment Directive will effectively remove the need for national type approvals.

"Instead," says the LPRA, "there will be a system of self declaration by manufacturers that their products conform with the appropriate ETSI Standards. This will be policed by market surveillance by as yet unspecified bodies."

Manufacturers of radio systems as diverse as security systems and mobile phones are rightly worried by the apparent relaxation of the radio systems approval rules this represents. The natural concern is that such is the vagueness of the proposed surveillance system it will fail to prevent substandard equipment entering the market, whether from inside or outside Europe.

If the new rules allow for users in the UK to be sold inferior radio equipment, then the concern amongst the established manufacturers is that low power radio systems, like those working in the unlicenced 418MHz band which have been tested and type-approved at not inconsiderable expense, will be marked with the same 'dodgy' tag.

Manufacturers feel they have invested a lot of time and money in raising the public perception of low power radio systems by bettering the quality of their products. The last thing they want right now is for the EU regulators to turn the clock back with a free-for-all of untested products.

In the words of the LPRA: "Thereby bringing the industry into disrepute in the long term. In this relatively new area of technology it has been an ongoing process of persuading the market to have confidence in the efficient operation of well manufactured devices which conform to regulations."

But have the LPRA and its members anything to worry about? Self-certification of electronics products is nothing new. It has been part of Europe's electromagnetic compatibility (EMC) regulations for a number years.

The market does not appear to have been flooded with substandard and dangerous equipment as a result. However, this has not stopped some manufacturers from complaining about the potential loop-holes in the rules which self-certification can present to unscrupulous suppliers. And the EMC rules are being actively enforced.

So these are real and continuing concerns, which should not be dismissed out of hand by the regulatory authorities.

As the LPRA warns: "How the new Directive will actually be applied a d policed in different countries is still under discussion and there are complicated issues to address."

But the real kick in the teeth for radio equipment manufacturers is that they have spent money on third-party testing of their products which now seems to have been completely unnecessary.

Manufacturers in this country have good reason to be angry. After being asked by the authorities and their customers to invest in the necessary type approval of their products in the run up to the new directive, the bureaucrats in Brussels have decided to tear up the game plan at the eleventh hour.

Manufacturers fear that when the new rules on self-certification are introduced next year, they will have to compete with cheap imports from overseas manufacturers who have not had to bare the cost of type approval testing for their products.

This will create more unwelcome and unfair competition in the low power radio market. And the timing could not have been worse.

UK manufacturers are already grappling with a UK radio spectrum licensing cock-up which seems to expose some low power radio systems to interference from the Tetra mobile communications system now being deployed by the emergency services.

But this is not just a business issue. By opening the flood gates at the eleventh hour the European regulators have done nothing to reassure all us users who will be looking for that "best-buy" radio transmitter next year that we will necessarily be getting value for money. ■

Richard Wilson

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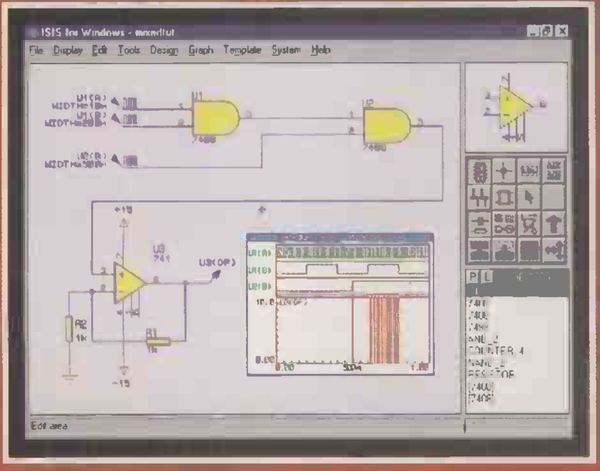

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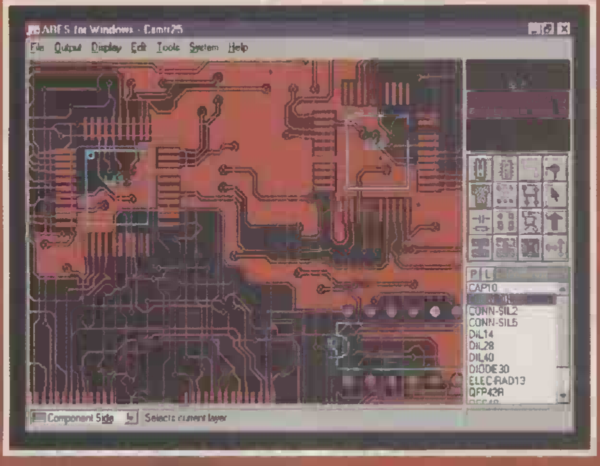

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UPDATE

BT could lose line monopoly

BT could lose control of the local loop this year, allowing its competitors access to the telephone lines going into consumers' houses.

If the government legislates on proposals of industry watchdog Oftel to free up the local loop, the UK could be in for the biggest upgrade to the telephone network in its 110 year history as rival operators rush to offer xDSL broadband access technologies like ADSL and cable modems to domestic users.

Oftel is expected to recommend following the US 1996 Telecommunications Act which said that any licensed operator wanting to provide an upgraded line to a customer can go to the local operator and demand control of the customer's line.

Traditional operators in the US like the Bell operating companies, and like BT in the UK, are reluctant to provide upgraded lines to customers at reasonable cost. This is because chips implementing xDSL technology exist that allow lines to be upgraded for $25, whereas operators charge businesses tens of thousands of pounds for upgraded lines. Businesses will obviously switch to cheap xDSL lines, so losing the traditional telecommunications operators a lot of revenue.

BT is under threat from several quarters. First there's Oftel and the British government; second there's the EU, which plans pan-European legislation this year to force operators to provide xDSL; and third there's rival operator Cable and Wireless, which is going to offer an xDSL alternative technology – cable modems – to its customers in the second half of the year.

BT is expected to fight all the way. BT's financial director is said to have told an investments bankers' conference that the company will make an announcement on asymmetric digital subscriber line (ADSL) technology roll-out in August. But in another report BT is said to have threatened the government that it will not offer ADSL if the local loop is opened to competition. That would ruin BT's business further as rivals rush in to provide xDSL broadband access over their networks.

Telecoms industry will be hit by EU approvals changes

The EU's controversial decision to scrap type approval requirements for telecoms and radio products will hit UK manufacturers and the BABT telecoms approvals body next year.

BABT is being forced to move away from approvals to compliance testing in response to the EU directive, which states that from April 2000, approval by a notified body will not be required for telecoms and radio equipment. Instead the onus for standards compliance will be on the manufacturer. "Basically that means we will lose all our business in April," said a BABT spokeswoman.

Manufacturers of radio systems as diverse as security systems and mobile phones are worried by the apparent relaxation of the radio systems approval rules this represents.

According to the Low Power Radio Association (LPRA), the proposed Radio & Telecommunications Terminal Equipment Directive will effectively remove the need for national type approvals. "Instead there will be a system of self declaration by manufacturers that their products conform with the appropriate ETSI standards. This will be policed by market surveillance by as yet unspecified bodies," said the LPRA in a statement.

BABT has already teamed up with test house TöV Product Service to become BABT Product Service and will offer testing and compliance checking for telecoms and radio. It will be able to supply a voluntary approval certificate which will give manufacturers confidence that their products meet all the relevant specifications.

The spokeswoman claimed that although companies will be able to self certify products, if anything goes wrong their branding and company name will be blemished. "Do you really want the onus of blame to come to yourself when we can still help you?" asked the spokeswoman.

Melanie Reynolds *Electronics Weekly*

Electronic, I am... Hasbro's Star Wars figures, released to go with the new film Episode 1, come with an audio microchip in their bases. The CommTalk Reader, which can be bought separately and complements the figures, allows them to talk by downloading their speech and storing it. This is a new toy technology that reads four key phrases of dialogue for each character, and sound effects from the film, which opened in the UK on 16 July.

Mobile mast sites – public to get more say

The government is to give the public more time to comment on proposed mobile phone masts as part of changes to its guidelines.

Its new circular, Planning for Telecommunications, also provides for stronger planning control for sites of special scientific interest.

Responding to a written parliamentary question, Minister for Planning Richard Caborn said the changes include a new 42-day prior approval procedure for telecoms masts. This includes erecting a notice publicising proposed development.

"The circular sets a clear policy framework for planning for telecommunications development to keep environmental intrusion to a minimum," added Caborn.

The government wants local planning authorities and industry to adopt a more active role in identifying the best environmental solution for the masts. To help bring this about, said Caborn, pre-application discussions between the parties will examine the various sitings and designs options.

The order making this change has already been presented to parliament and came into force on 9 July.

UK spending on electronics R&D drops

Electronic and electrical companies are investing less on research and development than at any other time over the last three years.

Total expenditure of £763m in 1998 was 16 per cent down on the year before. Electronics and electrical companies spent 3.2 per cent compared to a national average of 1.9 per cent. But the top three companies – GEC, Racal Electronics and Siemens – account for two thirds of the total spent.

Generally the scoreboard shows the UK is not achieving the levels of R&D investment reached internationally, which the Unit feels could indicate a lack of commitment to growing into the large technology companies of the future.

"Tomorrow's profits come from today's R&D," commented Norman Price, an industrialist on secondment to the Unit.

According to the 1999 R&D Scoreboard from the DTI Innovation Unit the UK's largest R&D investor, GEC, ranks ninth out of 28 companies on an international scale. The average spend at international level is 5.3 per cent, which means the UK is lagging behind, although GEC at 6.3 per cent is ahead of the game.

Ultimate connection... The final winner in broadband-to-the-home will be fibre optics – replacing xDSL, cable modems, satcomms, and terrestrial broadcast, it is claimed. Ericsson Cable's Ribbonet system (pictured) can inject optical cables into existing cable conduits.

In-car satellite radio drives a step nearer

Digital satellite radio beamed directly to cars is closer to reality in the US with the involvement of major car manufacturers.

Ford Motor Company said it has teamed with CD Radio to bring satellite radio broadcasts to its car owners for $10 per month with 100 advertising free channels. The digital radio receivers, however, will not show up in Ford cars until early 2001.

"CD Radio service will bring to radio what cable networks have brought to television," said Ford executive director Mike Ledford.

General Motors recently took a minority stake in CD Radio competitor XM Satellite Radio and said it will begin installing digital radio receivers in its cars and trucks by the end of 2001.

In addition to radio broadcasts, the digital receivers may also be capable of providing drivers with in-car access to e-mail and Internet-based navigation services.

Engineers are climbing the ladder

Electronics engineers feel their status within society has improved in the last 12 months, according to a recent survey.

A survey of almost 1300 engineers and managers in the electronics industry has indicated that concern over the poor status of engineers in the UK has eased from the alarmingly high levels recorded a year ago.

Just 65 per cent of those questioned in the telephone poll expressed concern over the status of engineers.

Although this represents considerable disquiet in the industry over status, the figure is significantly down on the 90 per cent of engineers expressing concern over their status in 1998.

In this latest survey just 36 per cent of those questioned felt strongly that poor status was still an issue within the UK.

This was another indication of how concern over the issue seems to be easing.

It seems that a more positive response to investment in the high-tech sector from the government may have bolstered the standing of electronics engineers within society as a whole.

The negative factor of semiconductor plant closures has also been off-set by the growing importance of the local design community – particularly in technologies for mobile communications and digital TV.

The poll also demonstrated the fears that engineers might be forced to move abroad to work by relatively poor pay and conditions in the UK seem to be unfounded.

Just 11 per cent maintained that working conditions in the UK were poor. Only nine per cent could see themselves working abroad on account of better working conditions, including salary.

Police electronic media powers look set to widen

The government is planning to widen police powers for intercepting telephone and postal communications to electronic media. It is asking service providers to comment on the impact this will have on businesses and costs.

The intention is to allow for the tapping of messages on e-mail, the Internet and other electronic media for the first time.

The proposals also bring private networks into the scope of the warrant system for the first time allowing people who believe their privacy has been unfairly invaded a right of redress.

Home Secretary Jack Straw has published a consultation paper on "Interception of Communications in the United Kingdom" and is asking communication service providers details of their business and the impact of the proposed new laws on their firm.

"Sophisticated criminal and terrorists have been quick to exploit a revolutionised communications industry," commented the Home Secretary.

Freeserve nets one in three domestic UK web users

Nearly one in three home users – 31 per cent – of the Internet use Dixons' Freeserve service, according to a survey by Fletcher Research. The second most popular service was BT ClickFree which attracted 14 per cent of users in the poll, which covered 40 000 users. It also predicts 12.5 million adults at home and work will be linked to the Internet by the year end.

FEI predicts boom in chip sales

A massive increase in the demand for integrated circuits is predicted next year, according to the Federation of the Electronics Industry's (FEI) annual semiconductor review and forecast of the component market.

The organisation predicts a 24 per cent increase in the value of the market, rising from an estimated £5.1bn for this year to £6.3bn.

Malcolm House, the FEI's economist, said the growth depended on manufacturers choosing to stay in the UK. "The government and manufacturers have to work together to ensure the equipment manufacturers remain in the UK," said House.

According to House, the extraordinary growth in 2000 will be driven through three industry sectors: set-top boxes, mobile phones and PC growth. The memory market will pick up this year and continue to grow into 2001. "Prices will stabilise. It is a difficult sector to predict but we are forecasting growth," said House.

Overall the FEI is expecting the total UK semiconductor market next year to grow in value by 22.7 per cent, compared to an estimated 13.4 per cent value growth this year. The market for discretes will also rise next year by 7.7 per cent, compared to 2.6 per cent value growth this year.

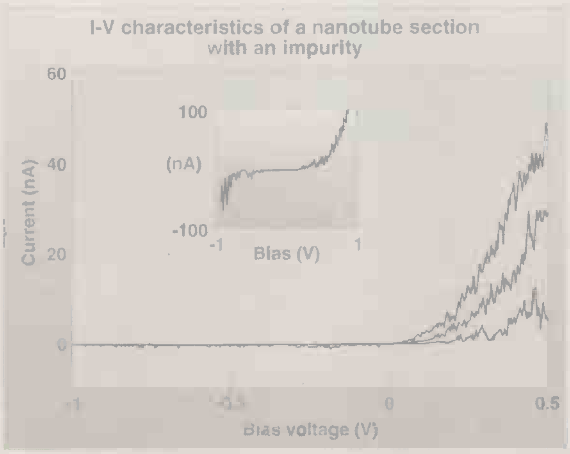
The optimistic forecast follows years of poor growth with an actual overall increase of the UK semiconductor market by 3.3 per cent last year, 1.1 per cent in 1997 and a decrease of 10.2 per cent in 1996.

Alex Mayhew-Smith
Electronics Weekly

Nanometric tube exhibits diode characteristics

US scientists have demonstrated a single-wall carbon nanotube behaving as a diode, writes Roy Rubenstein.

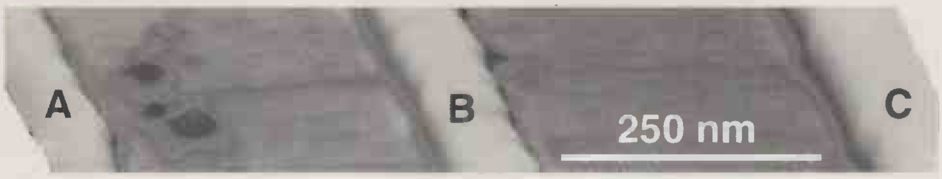
Nanotubes, made from a graphite plane of carbon atoms that are rolled up and sealed at the edges, are attracting research interest due to their inherently small structure. Ultimately they promise nanometre-sized circuits switching at terahertz speeds.



"It will probably be one to two decades before they are used in practical applications," pointed out Alan Johnson, assistant professor at the University of Pennsylvania, who has demonstrated the nanotube diode.

What Johnson and his team have shown is the effect impurities have on the electrical behaviour of nanotubes. "Nanotubes are highly sensitive to everything: roll it one way and it's a metal, roll it another and it's a semiconductor," said Johnson.

While laying a 600nm-long, 2nm in diameter nanotube across three gold electrodes (A, B and C – see picture), an impurity was placed near electrode A. The nanotube itself was rested on a silicon-dioxide insulator separating it from a highly-doped substrate.



Connecting first a negative and then a positive voltage across B and C, the current/voltage behaviour shown was symmetrical, as shown in the graph.

However, repeating the process with the voltage across A and B and a diode-like characteristic results. "We believe the impurity is acting as a dopant, totally changing the nanotube's electrical behaviour," said Johnson.

The current – tens of nanoamps when forward biased – may be minute but currents up to twenty times larger has already been demonstrated. This is a tremendous current density, said Johnson, suggesting that nanotubes could make excellent interconnects.

Johnson and his team are now experimenting with known impurities and their positions with respect to the nanotube to better understand how they alter its electrical behaviour.

Since nanotubes are so sensitive to impurities, creating active circuit elements will require "putting them [impurities] exactly where you want them", said Johnson.

Java is embedding itself

Java technology is winning support in the embedded systems market with three suppliers making announcements in the US last week.

Sun Microsystems introduced a compact version of its Java Virtual Machine called K virtual machine (KVM). It allows Java applications to run on sub-PC devices such as hand-held computers. And Hewlett-Packard introduced a compact version of its Java clone Chai called ChaiFreeze-Dry for electronic devices such as printers and embedded systems.

KVM is based on the latest Java 2 Standard Edition and was developed with Motorola, which demonstrated a pager running KVM with Microware's OS-9 RTOS.

Cheapest digital TV deal yet?

Cable & Wireless Communications is launching an all out attack on the digital TV market with its announcement of the cheapest deal available yet.

The package which includes a set-top box, telephone line rental and a basic channel package will be available for £9.98 per month in parts of Manchester and London this week. The company claims the same deal would cost £15.90 for other delivery systems.

TV e-mail and access to interactive services will be available from October and the services will be rolled out to other areas of the North West and Greater London by the end of the year.

Achievement of the century – the PC

The PC has been voted the top technological achievement of this century in a poll sponsored by communications company Harris. In a survey of 1,000 Americans, about 40 per cent said that the computer was the top technology invention followed by the television with 12 per cent, and the refrigerator, also with 12 per cent. ■

In recent years, designers have been putting increasing effort into reducing the supply voltage and power consumption of digital, analogue and mixed integrated circuits and systems.

This trend towards lower operating voltages has been brought about by a number of factors. Firstly, there is a need to reduce power dissipation in modern digital systems. Complete systems can be implemented on modern high-density integrated circuits. As chip components get closer together, the problem of heat dissipation increases. And break-down voltage between components on a chip reduces as geometries get smaller.

Secondly, the use of battery-operated portable electronic and wireless systems is increasing. Examples are cellular phones, portable PCs and wireless terminals, pacemakers, blood flow meters and auditory stimulators. All these benefit from lower power consumption, and all have small size and low weight requirements.

Thirdly, low-power solutions are spreading into other fields of applica-

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Low voltage design

Analogue ICs are appearing that will work from a single 1.5V cell. These building blocks use new topologies and to get the best from them, you need to understand how they work. This set of three articles reviews the state of the art in research and looks at commercial applications relating to low-voltage and low-power analogue design. Starting with an analysis of bipolar options, the authors provide the main design rules and tricks needed to build new functional blocks for low-voltage, low-power operation.

tion, such as filters, audio signal processing and EMI and EMC compliant systems. In particular, non-invasive sensors are being fully integrated on chip.

Finally, there is considerable scientific interest in exploring the technological and physical limits of integrated devices.

These factors fall into two main categories: the increasing demand for long-life portable equipment and the technological limits of VLSI circuits. As for the portable applications, low power requirement usually implies a sacrifice in terms of speed and/or dynamic range, while high speed and high integration density are the basic aims of VLSI research.

The best way to reduce power dissipation in VLSI digital circuits is to decrease the supply voltage. A decrease in supply voltage is necessary because the electrical field within the chip has to be maintained at an acceptable level.

The panel entitled 'Scaling supply voltage' demonstrates the consequences of scaling down circuit dimensions. It also projects what sort of performance improvements are likely in the future.

For analogue applications, the rules are quite different from those for digital circuits. The supply voltage reduction does not imply an automatic power reduction, because this is set by the signal-to-noise ratio and by the bandwidth required for a proper circuit operation. Consider a typical g_m-C configuration. It can be proved that the minimum power consumption needed to sustain a sinusoidal output voltage swing with V_{pp} peak-to-peak amplitude, in a circuit supplied by voltage V_{dd} that realises a single-pole is,

$$P = 8kT \times f \times SNR \times \frac{V_{dd}}{V_{pp}}$$

For a rail-to-rail signal this becomes,

$$P = 8kT \times f \times SNR$$

Low-V, low-P requirements and limitations[1]

Reducing the supply voltage leads to the lowering of the power dissipation of digital cells. This is because the current consumption of CMOS digital circuits is directly proportional to the square of the supply voltage.

In analogue circuits though, when the supply voltage lowers, the power dissipation does not necessarily decrease. This is because the folding technique can replace the traditional stacking of transistors. Consequently, in order to decrease the power consumption in low-voltage analogue circuits, the topologies have to be kept as simple as possible.

Low-voltage topologies do not necessarily produce low power circuits. The main requirements for low voltage topologies are as follows.

For portable applications, low-voltage circuits need to be compatible with common battery voltages. They need to have low power dissipation, i.e. low current drain.

Low-voltage topologies need to offer the possibility for designing analogue functions with sufficiently high performance. In operational amplifiers, for example, this means full input and output swings, large gain-bandwidth product, etc.

In addition, low-power topologies need to allow the design of suitable current and voltage references and temperature insensitive circuits. In bipolar technology, for instance, base-emitter compensation is useful for improving performance.

These requirements have to be matched with the following main low-voltage limitations: threshold voltage, or base-emitter voltage; noise (in cur-

Scaling supply voltage

The reduction of supply voltage and power dissipation follows the scaling of the circuit dimensions, whose consequences are summarised below.[1] Scaling at a factor of K gives:

Vertical dimensions	K^{-1}
Voltages	K^{-1}
Impurity concentrations	K
Capacitances (per unit area)	K
Lateral dimensions	$\geq K^{-1}$
Propagation time	K
Power dissipation	K^{-1}

and for the MOS transistor:

g_m	1
S-to-n ratio	K^{-1}
Mismatch	K

Scaling at a constant field of a factor K means that scaling the physical dimensions of silicon devices is accompanied by a proportional reduction of the internal voltages. This is done to keep the electric field unchanged, allowing consistent comparisons

The next table shows an interesting comparison between the actual and future scenario of the main circuit performance.[12]

Feature	1998	2004
Supply voltage (high performance)	1.8-2.5V	1.2V
Supply voltage (low power)	1.2-1.5V	1V
Lithographic resolution	0.35mm	0.18mm
Channel length	0.15mm	0.07mm
Gate oxide thickness	200Å	80Å

Low voltage bipolar rail-to-rail op-amp[13]

The input stage of Fig. 6 can be completed by a suitable rail-to-rail output stage in order to implement a complete low-voltage op-amp. The main characteristics of such an op-amp, for 0.9V total supply voltage and 10kΩ R_{load}, 100pF C_{load}, are:

Input-stage swing	Rail-to-rail (V_{ss}–0.35V, V_{dd}+0.15V)
Output-stage swing	Rail-to-rail (about 94% of V_{dd}–V_{ss})
Input transconductance	Constant ($\Delta_{gm(MAX)}$=8.5%)
Gain bandwidth	0.7MHz (phase margin>45°)
Low-frequency gain	>112dB
Power consumption	0.46mW
Slew rate	0.1V/μs
Total harmonic distortion, 1kHz, V_{pp}=60% V_{AL}	0.01%
Equivalent input voltage noise	145nV/√Hz
Input bias current	150nA max.
Input offset voltage	<0.1mV
CMRR	>60dB
Temperature working range	0 to 80°C

rents); precision, speed, driving capability – especially in MOS – and the fact that low currents mean high resistances and consequently high noise. Note that threshold limitations affect the ability to stack transistors.

To compound the problem of designing low-voltage circuits, the architectures available for working at low supply rails are inadequate, as are existing models for transistors. Since this is a relatively new area there are also cultural lacunas and a rather low appreciation of the problems involved.

As a sum of all these factors, you can see that low-voltage design calls for an efficient use of the supply voltage range. In many wide range applications this implies the target of rail-to-rail input and output stages.

On the contrary, the power limitations are mainly linked to,

- parasitic capacitances – with consequent increase of the power necessary to achieve the bandwidth constraints;
- traditional current-inefficient amplifiers – the power spent in bias circuitry is wasted and has to be minimised;
- peak-to-peak amplitude limitations – some stages are required to have a peak-to-peak voltage range as close as possible to the total supply voltage;
- noise – coming from the power supply or generated on chip by other circuit modules;
- low g_m/I ratio – in MOS, working in strong inversion;
- need for precision – which generally leads to the use of larger size active and passive devices;
- clock power dissipation in switched capacitor circuits.

As a result of these factors, low-power design demands an efficient use of the supply current. In particular, this can be achieved by the use of specifically designed low-voltage class-AB output stages and an efficient frequency compensation strategy.

The combination of these constraints and requirements gives the basic rules to be followed in order to design circuits capable to operate at low supply voltages with reduced power dissipation.

Bipolar versus CMOS technology[1]

A delicate point concerns the choice of the technology. Bipolar and CMOS technologies each have advantages and disadvantages, summarised as follows.

Bipolar advantages: transconductance higher than CMOS – and consequently, higher bandwidth; collector-emitter voltage lower than corresponding drain-source voltage;

Widlar's low-voltage amplifier[8]

Widlar's operational amplifier is able to operate at a supply voltage of 1.1V. A simplified schematic of it is shown below.

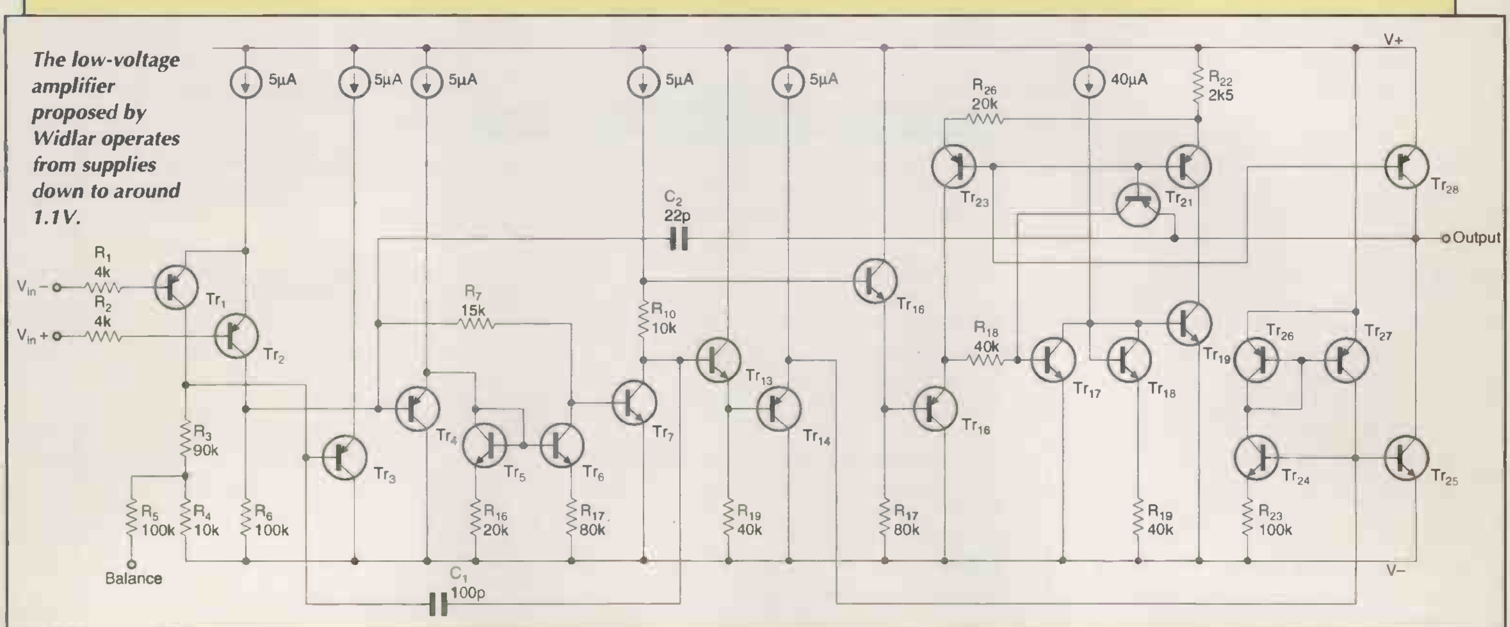
Its input stage is made up from lateral p-n-p transistors Tr_1 and Tr_2. These are used to ensure proper operation at common-mode voltages near or equal to the negative supply voltage.

Proceeding through the circuit, the input signals are buffered by the vertical p-n-p followers, $Tr_{3,4}$. The outcoming differential signal is converted to single ended form by $Tr_{5,6}$ and fed to the base of the second stage amplifier *Tr7*.

From the collector of Tr_7 the signal is split, in order to drive the two separate halves of the complementary class-B output stage. The n-p-n output transistor, Tr_{25}, is driven directly by $Tr_{13,14}$. This complementary emitter-follower arrangements is unavoidable in very-low-voltage applications, since it provides the necessary current gain without requiring the extra diode voltage biasing of a Darlington connection.

Transistors $Tr_{24,26,27}$ form a boost circuit that increases the available drive as a function of load current. Excess boost current is absorbed by Tr_{14}. Drive for the p-n-p half of the output is more complicated, due to the need to maintain circuit balance and to obtain the correct phase relationship and DC level shift.[3]

This following circuit is the first example of low voltage operational amplifier in bipolar technology, and is used in National Instruments' *LM10*. It has an internal bandgap reference voltage, described in a further panel, and its main characteristics are: minimum-maximum supply voltages of 1.1-40V, amplifier supply current 0.3mA, DC gain 50000, gain bandwidth 70kHz and input offset voltage 0.3mV.



The low-voltage amplifier proposed by Widlar operates from supplies down to around 1.1V.

base-emitter voltage more predictable and lower than the threshold voltage of CMOS — especially in the past.

CMOS advantages: design simplicity – greater degrees of freedom; significantly lower costs; high input impedances; a cut-off frequency not dependent on supply voltage and quiescent current; threshold voltage tuneable in some technologies.

As you will see from **Table 1**, bipolar and CMOS have complementary properties, which can sometimes help the choice of the proper technology.

Recently, the reduction of the threshold voltage in the CMOS technology has definitely directed the low-voltage design towards this technology. This reduction is related to oxide thickness, doping, dielectric constant and internal working voltage.

In CMOS technology, it is important to choose the right working region for the MOSFET, because this can improve the circuit performance.

A device operating in weak inversion has some advantages relative to one working in strong inversion. Its behaviour is similar to a bipolar device. It has a lower drain-source voltage, gate voltage and gate capacitance. In addition, it has a higher g_m/I ratio.

However, strong inversion operation is better for reduced output noise for a given drain current and low current mismatch, leading to precise current control. It is also best if high operating speeds are needed.

Sometimes, it is not possible to choose the operating condition of a transistor. It depends on the threshold voltages values, and, in particular, on the process technology and the circuit topology. Especially when the supply voltage is very small, due to the voltage drop caused by the circuit topology, the transistor itself is often working in weak inversion.

Low-voltage low-power circuits overview

The most demanding low voltage operation requirement is operation from a single cell. This means minimum operating voltages ranging from 0.8V for a discharged cell to 1.6V for a fully charged cell.

Conventional circuit architectures are not generally adequate for single or dual-cell operation. Consequently, there is a need for new architectures specifically for low voltage circuits. As a result, analogue as well as digital circuit designers have been forced to redesign a number of functions and subsystems capable of operating at supply voltages as low as 2.4V and even 1.2V.

In this context, designers are usually faced with three different options.[2]

They can stick to traditional topologies, provided that they are able to work at lower supply voltage without performance degradation. They can make appropriate use of complementary topologies – p-n-p/n-p-n and pMOS/nMOS. Or they can redesign the circuit, considering that the stacked architectures can often be replaced by their folded counterparts.

Take **Fig. 1** as an example. It shows a Darlington current amplifier. The 'stacked' topology of Fig. **1a)** works at a minimum supply voltage of 1.6V. The 'folded' solution, Fig. **1b)**, allows this value to be reduced to 0.9V.

Another example is the cascode stage, **Fig. 2**. It is shown in its two topologies – the traditional stacked version, Fig. **2a)**, and the low-voltage folded solution, Fig. **2b)**. Also in this case the folded topology works at lower supply voltages.

Bipolar analogue designs[3,4,5]

Low-voltage input stages. In order to obtain the maximum input voltage range, two input differential pairs can be placed in parallel. **Figure 3** illustrates this type of input stage.

The n-p-n pair, $Tr_{1,2}$, operates correctly in the upper portion of the common-mode voltage range while the p-

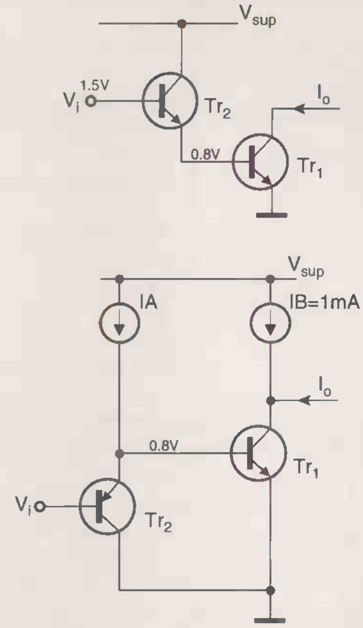


Fig. 1. At very low voltages, the stacked Darlington in a) becomes impracticable so the folded version in b) is used.

Table 1. Comparison of the two main technologies available for low-voltage, low-power design.		
Property	**MOS**	**Bipolar**
DC current control	No	Yes
Current noise	Low	High
Flicker noise	High	Low
Voltage switch	Yes	No
Current matching	Low	High
Voltage offset	High	Low
Thermal control	Bad	Good
Cut-off frequency f_T	Low	High

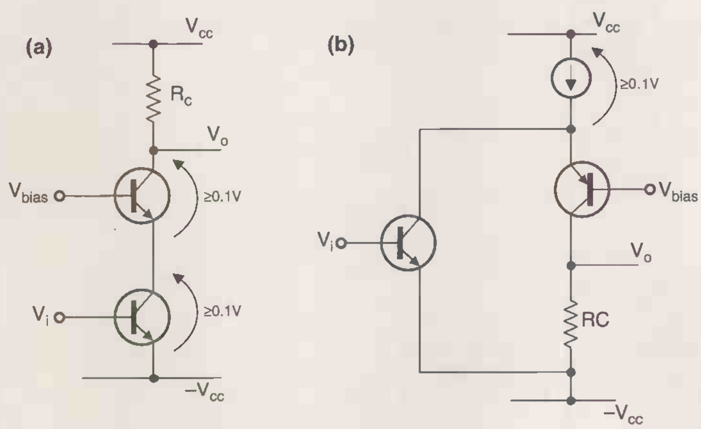


Fig. 2. Another example of the traditional stacked cascode, a) and the folded cascode, b), which is more suitable for low voltage operation.

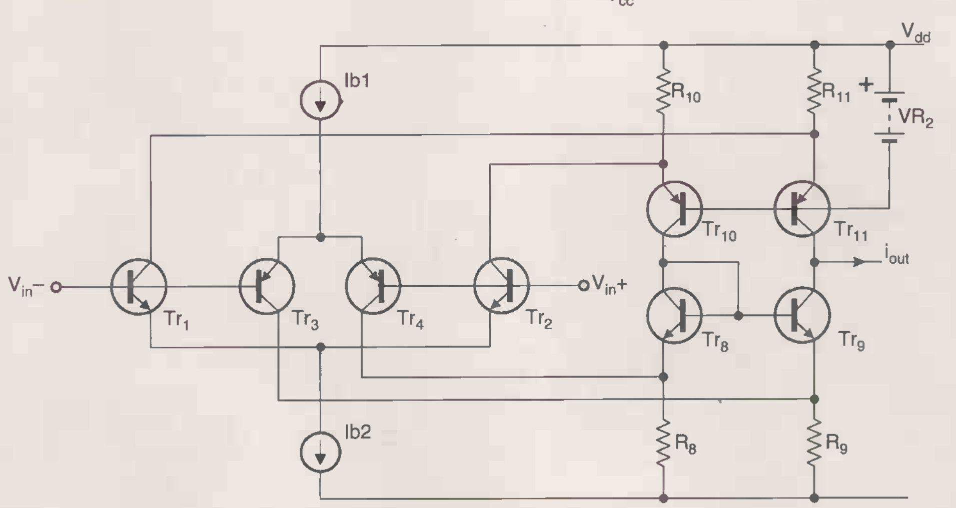


Fig. 3. To make the most of a low-voltage op-amp, it needs to have a special rail-to-rail input stage.

An op-amp architecture that runs from a 0.78V supply[13]

A bipolar op-amp was designed for low voltage sensor applications with the following basic requirements:

Operating temperature range	–20 to +80°C
DC gain	≥80dB, load ≥1kΩ
Gain bandwidth	≥500kHz
Phase margin	>45°, capacitive load ≥100pF
Input offset voltage	≤1mV
Input noise	≤15nV/√Hz, R_{source}=0
Output current	≥5mA
Capacitive loads	≥100pF
Supply voltage range	0.9-12V
Supply current	≤1mA
Output swing	≥90% V_{al}, load ≥10kΩ

The op-amp, shown in the diagram below, also had to have a wide common mode input voltage range, including ground so that it could operate from a single supply rail. And it had to have a four quadrant operation output stage.

The circuit topology has been developed in order to achieve the requested performance of full output swing (rail-to-rail operation). This is related to the need of having a large enough dynamic range and a good current capability at the lowest supply voltage.

This performance cannot be obtained by conventional topologies. The simple complementary emitter follower configuration can only operate with a V_{cc} of 1.8V or more and it does not allow rail-to-rail operation.

In low-voltage op-amps, a push pull complementary common emitter configuration is generally mandatory to provide large output voltage swings. Unfortunately, such stages require extra circuitry for bias stabilisation and make frequency compensation of the whole op-amp more difficult.

The n-p-n output transistor Tr_{on} is directly driven by the input voltage V_{in}, while the p-n-p transistor Tr_{op} is driven by a transconductance amplifier made up from $Tr_{11\text{-}14}$.

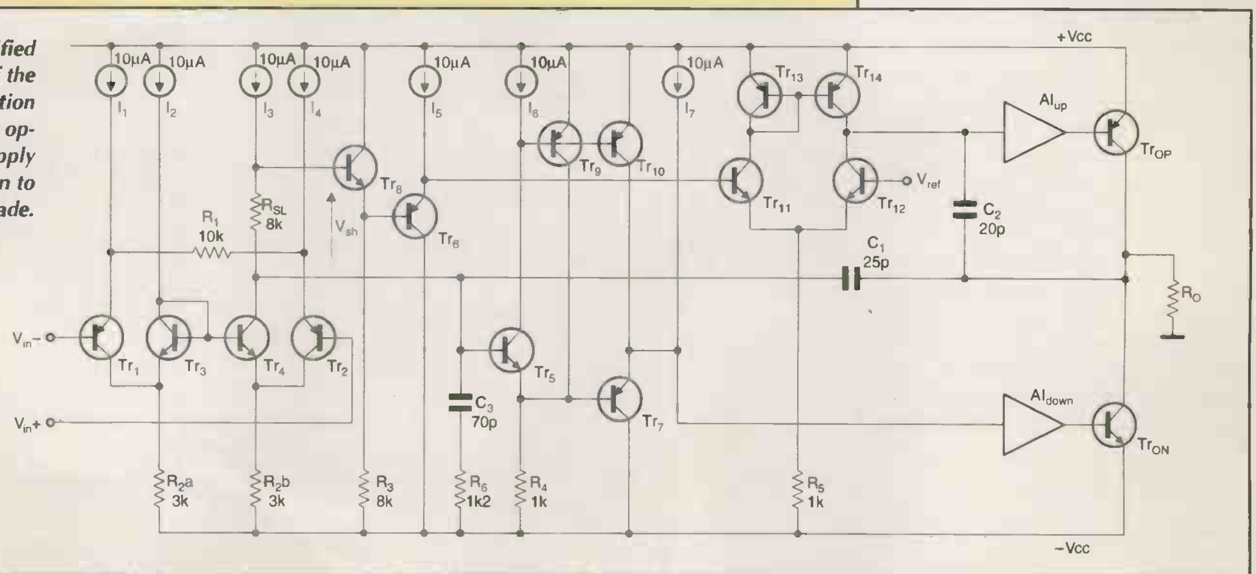
Shifting voltage V_{SH} is used to control the quiescent current I_Q of the output transistors Tr_{on} and Tr_{op}. Contrary to common-mode feedback loops, I_Q stabilisation mechanism is embedded in the same signal path circuit. This results in reduced complexity, simplified frequency compensation and potentially lower supply voltage.

Current amplifiers AI down and AI up can provide the extra base drive current without demanding too much bias from the supply rails. They are a modified implementation of the current amplifier presented by Widlar,[2,3] in order to extend its range of applications to high impedance input sources.

In the following the measurement results, taken from ten samples, in the condition of loading resistance of 1kΩ and at 20°C of temperature are presented.

Minimum supply voltage	0.78V
Low frequency gain	80dB
Gain bandwidth product	0.7MHz (PM=60°)
Supply current (at 1V)	750μA
Output voltage swing	90% of $V_{cc}-V_{ee}$
Input voltage range	(-0.3, Vcc-0.7)
Input offset voltage	400μV, averaged
Distortion, G=–1, f=1kHz, V_{out}=0.6V_{pp}, V_{al}=0.8V	< 0.15%
Slew rate	0.1V/μs
Overload recovery time (50% overload)	about 5μs
CMRR(f = 50Hz)	100dB
Equivalent input noise voltage, f=1kHz	15nV/√Hz
Temperature range	–20 to 80°C

Simplified schematic of the new configuration that allows op-amps with supply rails down to 0.78V to be made.



n-p pair, $Tr_{3,4}$ operates correctly in the lower part of the common-mode voltage range. Input transistors combine with common-base transistors $Tr_{8\text{-}11}$ to form a complementary folded cascode stage. Here, the differential signal currents coming from the input stage are summed and converted into a single ended output current.

The operating regions for the common-mode input voltages versus supply voltage V_{sup}, which is V_{dd}+V_{ss}, are depicted in **Fig. 4**. The main issue that can be drawn from this figure is that the minimum supply voltage at which the input stage has a rail-to-rail input voltage swing is 1.6V. Below that value, either one of the input pair is able to operate near one of the supply rails.

In the middle of the common mode input range, though, there is a gap where both the pairs are off because both I_{b1} and I_{b2} are saturated. Moreover, the input stage of the Fig. 3 shows a serious drawback. If the common-mode input voltage is moved from one range into another, the sum of the tail currents changes by a factor of two. Consequently, so too does the transconductance of this input stage. This, in turn, makes the frequency compensation difficult and induces large signal distortions.

Therefore, the need arises for an input stage with the same rail-to-rail capability, but with a more constant transconductance.

Input stages with constant transconductance

If the sum of the tail currents biasing the input pairs is kept constant, the drawbacks previously described can be overcome. Since the transconductance of a differential pair is directly proportional to its current, the total transconductance is also made constant.

A circuit that realises this principle is depicted in **Fig. 5**. If the common-mode voltage is near the negative supply rail, the p-n-p pair is activated by the current source I_{b1}. If the common-mode voltage is moved higher than a certain threshold, current source I_{b2} supplies the n-p-n pair.

Note that if the sum of the biasing currents is made constant, the transconductance can be kept constant, even within the turn-over range of the switches. Therefore an improved rail-to-rail input stage can be obtained. The rail-to-rail capability continues to exist if the supply voltage is equal or higher than 1.6V.

Rail-to-rail input stage operating at a volt [5,6]

In order to lower the supply voltage without degrading the amplifier performance, a new topology has to be considered, **Fig. 6**. Here, level-shift resistors R_{SL1}-R_{SL2} and current source/sinks Tr_{SL1} and Tr_{SL4}, are inserted between the input terminals and the bases of the n-p-n and p-n-p input pairs.

Two complementary pairs, $Tr_{1\text{-}4}$, have been placed in parallel in order to achieve the rail-to-rail operation. Transistors $Tr_{5\text{-}7}$ operate as a switch. They help to keep the input stage output current constant with respect to any variation of the input common-mode voltage. In this way, the p-n-p stage is in conduction only for a limited range of the input voltages.

Bias voltage V_{bias} sets the limit. In this design the level shift network doesn't significantly affect the input bias current and the input offset of the amplifier. The shifting currents, provided by transistors Tr_{SL1} and Tr_{SL4}, are not constant here. On the contrary, they are controlled by sensing the difference between the emitter voltages of the two complementary pairs, ΔV_{EPN}, by means of transistor Tr_8. The level-shifting currents are adjusted to the desired value by means of transistors Tr_9 and Tr_{12}.

Resistors $R_{3\text{-}4}$, between the collectors of transistors Tr_3 and Tr_4, reduce the dependence of the differential gain on the input common mode voltage $V_{in(CM)}$. The equivalent voltage input noise is about 145nV/√Hz, the input offset voltage is 1.5mV, the power consumption is 45mW and the estimated chip area is of about 0.05mm^2. The shape of the level-shift voltage is shown in **Fig. 7**.

In the panel entitled 'Low-voltage rail-to-rail op-amp', the specifications for an operational amplifier created using the described input stage and a suitable output stage are presented.

Low-voltage output stages

The output stage of a low-voltage op-amp has to deliver a voltage signal that is as large as possible. This excludes the use of emitter followers as output transistors, because of the voltage drop of one diode voltage. Therefore, most low-voltage op-amps feature a complementary common-emitter class AB output stage.[7]

The main problems to work out with complementary common emitter class AB output stages are twofold. Firstly there is the idle current stabilisation versus temperature and supply voltage. Secondly, the problem of providing enough current gain in all operating conditions to retain low-power

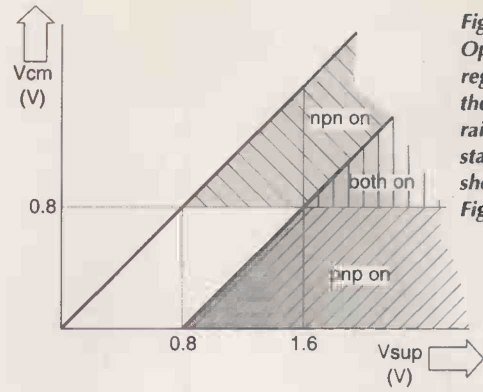


Fig. 4. Operating regions of the rail-to-rail input stage shown in Fig. 3.

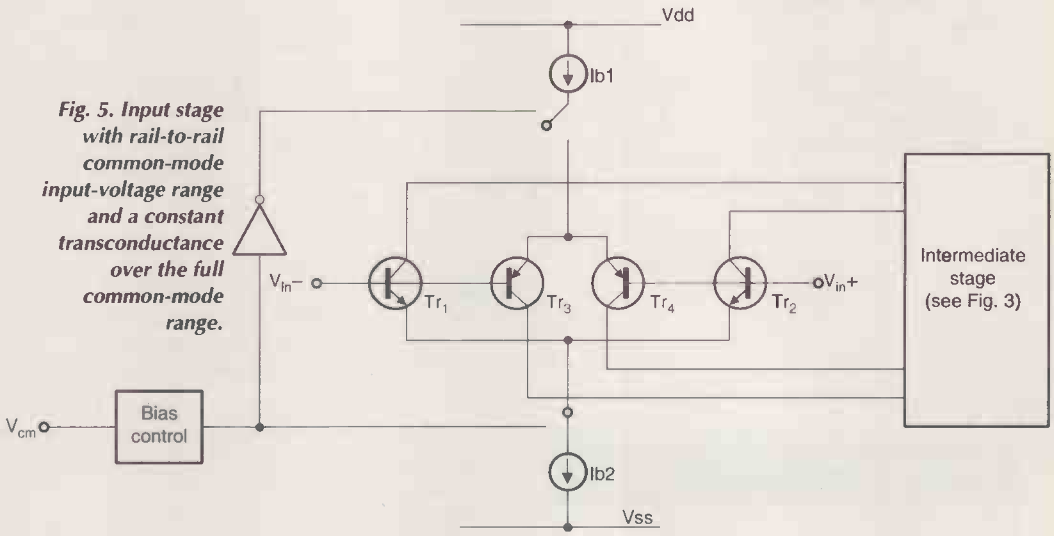


Fig. 5. Input stage with rail-to-rail common-mode input-voltage range and a constant transconductance over the full common-mode range.

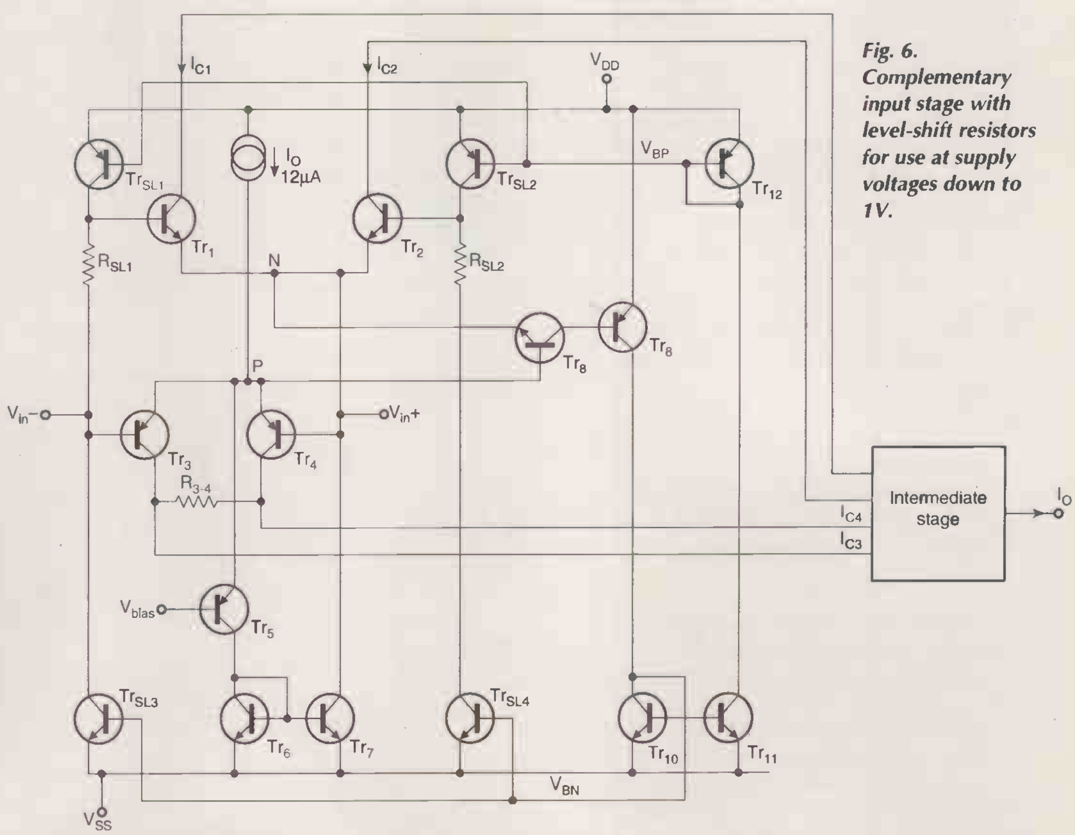


Fig. 6. Complementary input stage with level-shift resistors for use at supply voltages down to 1V.

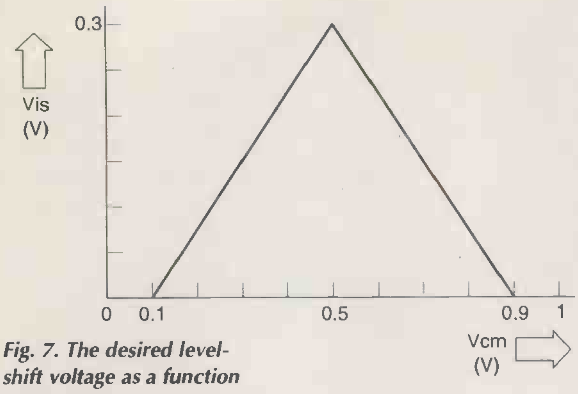
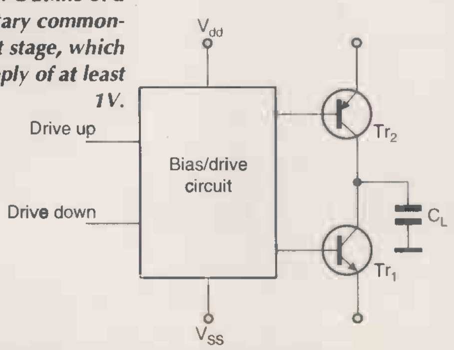


Fig. 7. The desired level-shift voltage as a function of the common-mode input voltage.

Fig. 8. Outline of a complementary common-emitter output stage, which requires a supply of at least 1V.



operation and sufficient amplifier efficiency. Included in these operating conditions is saturation, since at low V_{ce} voltage transistors are saturated.

Common-emitter output stage. In **Fig. 8**, the block scheme of a complementary common emitter output stage is presented. The common-emitter topology is driven by a bias/drive circuit control.

The minimum supply voltage of this stage is about 1.0V and depends on the emitter-area of Tr_1 and on the maximum current that has to flow into the load.

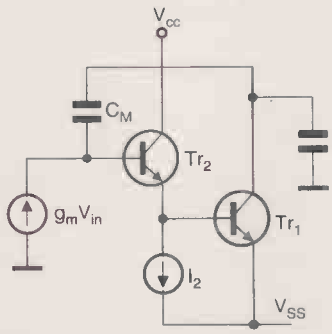


Fig. 9. Here is the n-p-n side of a typical output stage using a Darlington to increase current gain. This configuration needs a supply of at least 1.6V.

Darlington output stage. In order to increase the current-gain of the common-emitter output stage, an emitter-follower can be added, as seen in Fig. 9, to realise a Darlington output stage.

Transistors Tr_1 and Tr_2 are the common-emitter stage and emitter follower respectively. Frequency compensation is realised by means of the Miller capacitor C_M that splits input and output poles. The minimum total supply voltage for this stage is about one diode voltage higher than the previous stage, which is about 1.6V.

Widlar output stage. The Darlington stage is not appropriate if the supply voltage is lower than 1.6V. For very low-voltage circuits, a suitable lower-voltage output stage has to be developed. Such a circuit is shown in Fig. 10. It is known as a 'Widlar output stage,' Widlar being the name of its inventor,[8].

Transistor Tr_1 has again a common-emitter configuration to ensure the

Band-gap voltage reference for low-V designs[14]

Band-gap voltage references are circuits that give a constant reference voltage, independent of external parameters such as temperature and supply voltage. These circuits are used in many types of analogue circuits for signal processing, such as smart sensors, sensor systems and a-to-d and d-to-a converters.

The band-gap reference voltage[3] can be obtained by thermally compensating the base-emitter voltage of a bipolar transistor. Normally, V_{be} has a negative trend of about –2mV/°C. An additional temperature compensation circuit is used to cancel the first-order temperature dependence on V_{be}.

A fraction of the thermal voltage V_t=kT/q, which has a positive thermal drift of 0.085mV/°C, is used, so that reference voltage V_{ref} is obtained as a linear combination of V_{be} and V_t, as follows,

$$V_{ref}=b_0\times V_{be}+b_2\times V_t.$$

Figure A shows the topology for the implementation of $b_1\times V_{be}$. The b_1 coefficient is obtained by the ratio of R_2 to R_1. To realise the fraction of V_t, the offset of a low voltage operational amplifier is obtained by mismatching the emitter areas of the input transistors. This offset is then increased by the gain of a non-inverting amplifier, **Fig. B**.

Fig. A. Part of a low-voltage band-gap reference providing the b1×Vbe function.

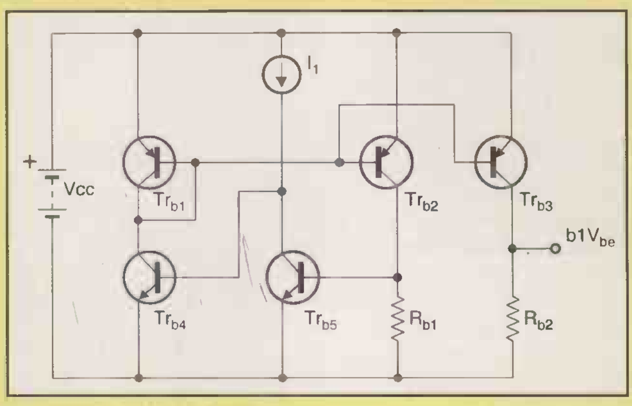
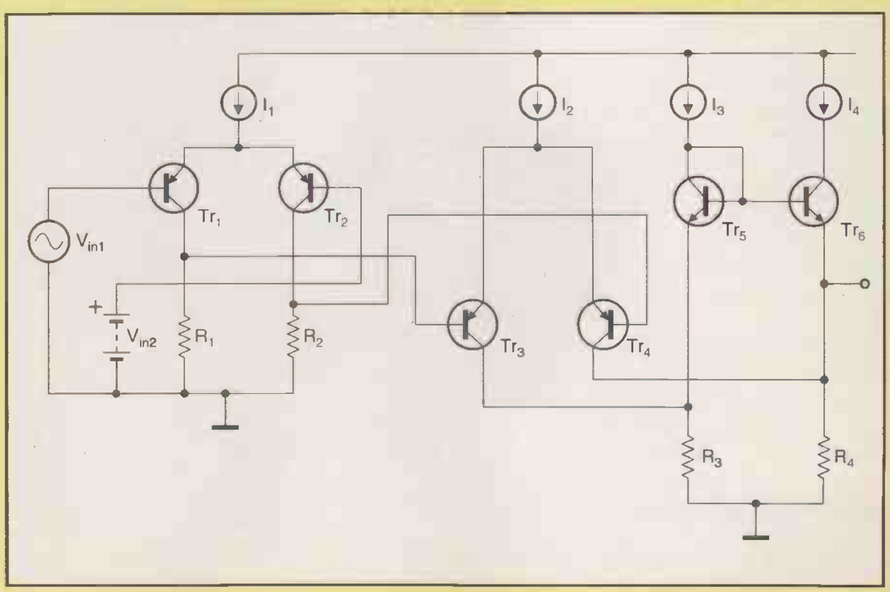


Fig. B. Compensation factor V_t is obtained by mismatching the emitter areas of an op-amp's input transistors and then amplifying the resulting error signal.



largest possible output range. The emitter-follower Tr_2 has its base-voltage very close to the negative rail, so the transistor Tr_3 restores a voltage level suitable to the correct operation of the intermediate stage.

Maximum output current is reached when all the current I_2 flows into Tr_1 base, and is given by $I_{1(max)}=I_2\beta_{sat}$, where β_{sat} is the saturation gain of Tr_1. When high output currents are required together with low power consumption, i.e. a low value for I_2, an additional current gain stage is inserted in front of the output stage. This stage of course has the same requirement for low-voltage operation.

The Widlar current-boosting circuit shown in Fig. 10, consisting of Tr_4, Tr_5 and Tr_6, meets all these requirements. Its operation is based on a careful control of the embodied positive feedback loop, tamed by the emitter resistance of driver Tr_2. This positive feedback mechanism greatly enhances the available current gain at the base of output transistors.

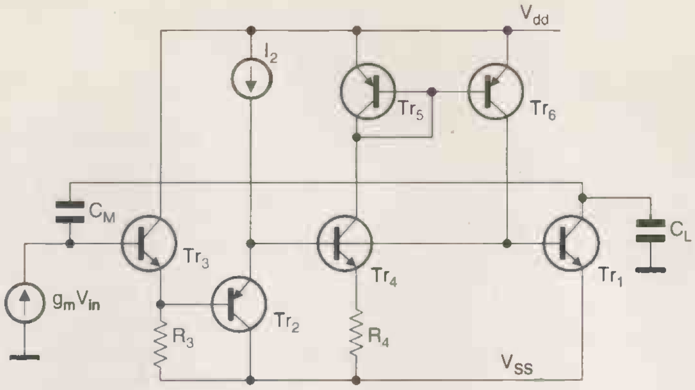


Fig. 10. N-p-n side of the Widlar output stage designed specifically for low-voltage analogue applications.

Miller capacitor C_M splits the input and output poles. A pole splitting mechanism for CMOS technology will be discussed in a subsequent article.

The minimum supply voltage is about 1.0V and depends both on the sizes of transistors and on the current that has to be driven into the load.

Widlar output stage architecture is capable of operating at a very low supply-voltage value and the current gain can be very high. However, its high-frequency behaviour is affected by the presence of two emitter followers preceding the output transistor;

Biasing bipolar devices using a PTAT[13]

This bias circuit is based on a simple low voltage proportional-to-absolute temperature reference, or PTAT, which provides constant bias versus supply voltage and relatively low variations versus temperature.

The complete circuit is shown. Resistor R_0 with Tr_0, Tr_1, Tr_2 and Tr_3 form the PTAT core. Reference current I_{ref} is defined by the following relationship,

$$I_{ref} = \frac{V_t}{R_{PO}} \times \frac{\ln(n)}{n}$$

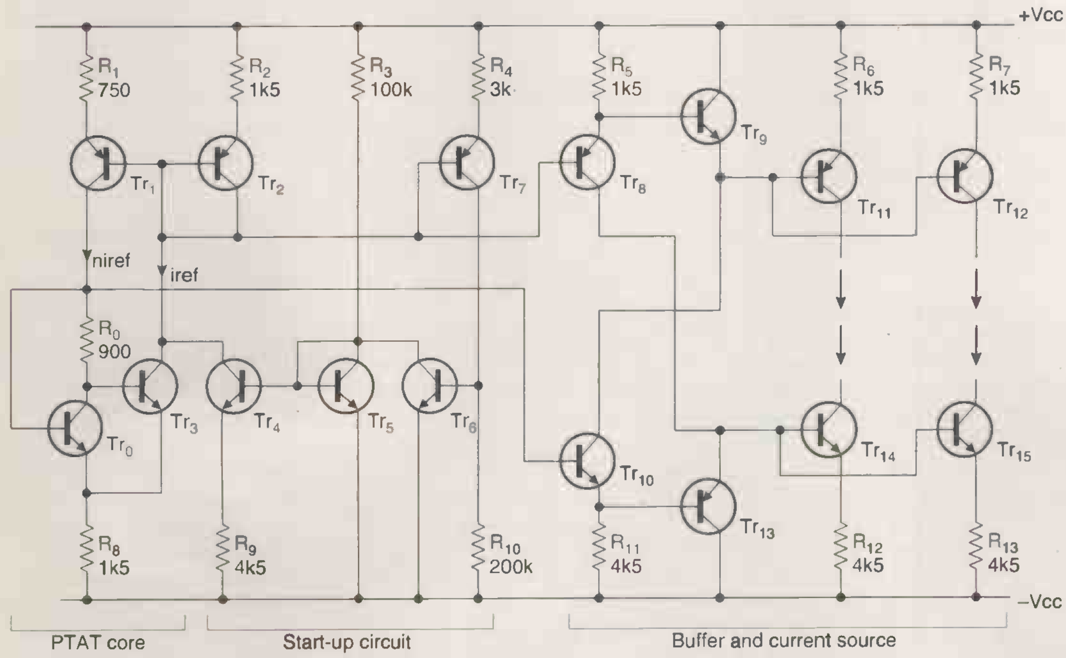
where n is the ratio of the areas of Tr_1 and Tr_2.

In practice, using an R_{P0} of 900Ω and n=2 yields I_{ref} reference current of 10μA at room temperature, 8μA at –40°C and 12μA at 80°C.

The PTAT bias generator circuit is buffered from the current source biasing the op-amp, i.e. $Tr_{11\text{-}15}$ by the voltage followers made up from $Tr_{8,9}$ and $Tr_{10\text{-}13}$. This prevents PTAT circuit operation from being affected by occasional saturation of the biasing current sources of the op-amp, when the output swing is close to the supply rails.

Resistors R_3, R_4, and R_{10}, together with $Tr_{4\text{-}7}$, serve as a start-up circuit.

Biasing circuit for bipolar devices operating at low supply voltages.



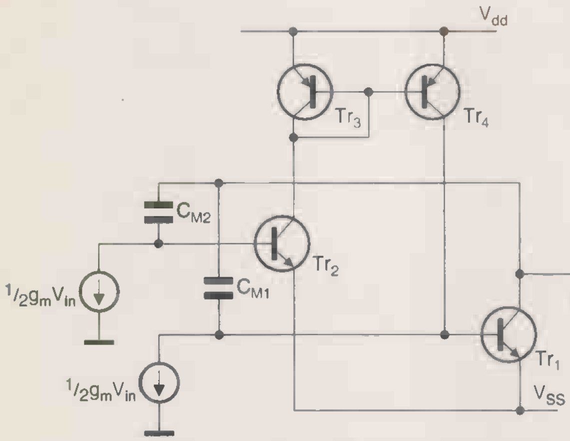


Fig. 11. Multi-path-driven output stage, n-p-n side. This circuit is very efficient when operating at low voltages.

this means that the second and third order poles need to be split locally with an extra Miller capacitor.

Multi-path-driven output stage.[9] In the previous section we showed that high frequency behaviour deteriorates if emitter followers are placed in front of the common-emitter output transistor. However, the need for high current-gain prohibits the use of a one-transistor common-emitter stage.

As a consequence, a circuit that combines a high current gain with the good high-frequency behaviour of a single transistor common-emitter stage has to be exploited. This circuit, called multi-path-driven output stage, is shown in **Fig. 11**.

Transistors Tr_2, Tr_3 and Tr_4 drive the common-emitter output transistor Tr_1. In parallel with this path, there is a 'feed-forward' path directly from the intermediate stage to transistor Tr_1. It ensures a good high-frequency performance, while transistors Tr_2, Tr_3 and Tr_4 supply the necessary current gain.

Note that the intermediate stage has to drive the output stage by means of two, identical-in-phase, input current-signals. The poles, at the outputs and at both inputs, are split with the Miller capacitors C_{M1} and C_{M2}.

The minimum value of supply voltage can also be very low, i.e. 1.0V. From the bases of Tr_1 and Tr_2 to the output, the current gain is $0.5\beta_1(\beta_2+1)\approx 0.5\beta_1\beta_2$. This value is about half the value of the Darlington stage. Because of these characteristics, the multi-path driven output stage can be considered very efficient.

A low-voltage solution for bipolar operational amplifiers is discussed in the panel entitled 'Widlar low-voltage amplifier'. This is the very first bipolar low-voltage op-amp – developed in 1978. The panel entitled 'An op-amp architecture that runs from a 0.78V supply' describes the lowest supply voltage solution for bipolar designs. This solution can operate from rails as low as 0.78V. In the panel entitled 'Band-gap voltage reference for low-V designs' is the circuit for a bipolar band-gap voltage reference, while in the panel 'Biasing bipolar devices using a PTAT' a biasing current topology known as PTAT is presented. ■

The next article on this topic looks at CMOS options for low-voltage and low-power analogue circuits.

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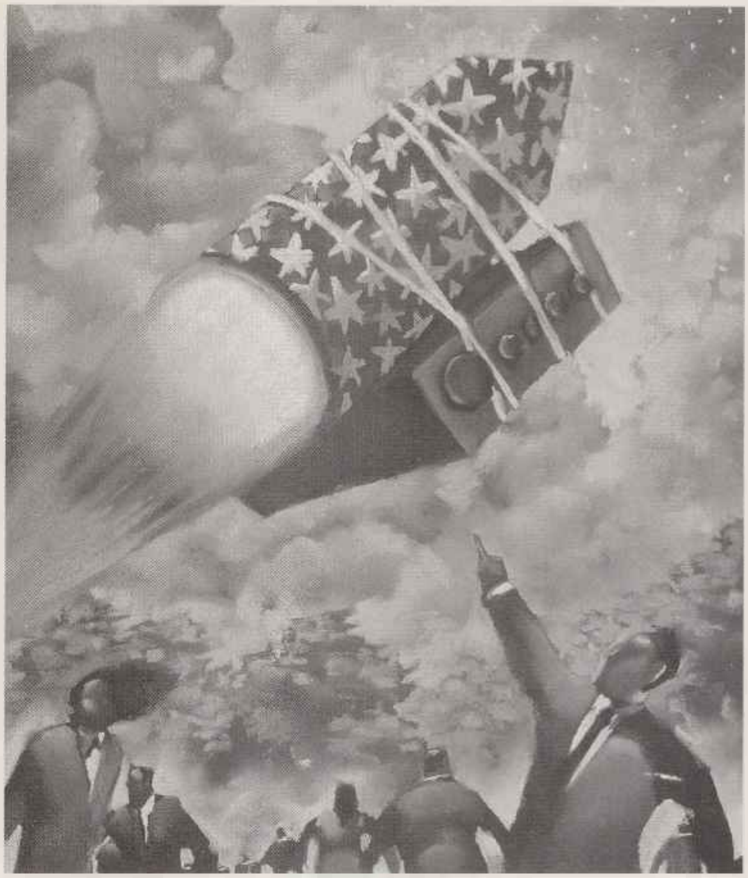
Yuri Ezhkov describes his 90W, 70V/µs power amplifier featuring a novel equaliser in its feedback loop.



Fast audio power

In my view, the influence of amplifier speed on perceived sound quality has not been investigated enough. Depending on maximum output power, the slew rate needs to be at least 4V/µs to remove dynamic distortions. But to allow the negative feedback circuit to correct for small dynamic distortions, the slew rate needs to be considerably greater than 4V/µs.

Negative feedback generates new higher-order harmonics due to band-pass nonlinearities in each cascade. These harmonics frequently limit the amount of negative feedback that can be applied. This means that an increase of negative feedback should be accompanied by a reduction of inherent nonlinearity in the amplification cascades and by an improvement of their high-frequency properties.

When designing the amplifier described here, I had the following goals in mind,

- Use of amplification cascades with the best possible linearity and bandwidth
- Fastest speed possible
- Rail-to-rail output swing
- Good overload capability
- A global negative-feedback circuit with a high/low equaliser that could be disconnected
- Facilities for optimising general negative feedback level
- Application of common components.

Cascades based on FETs, in particular differential cascades, have the least nonlinearity. A problem with transistor amplifiers is thermal distortion. This problem can be resolved by means of cascodes involving a fixed collector-to-emitter or drain-to-source voltage.

The input stage of the amplifier is a differential common-source-common-base cascode using a matched pair for transistors $Tr_{4,5}$. A peculiarity of the input cascade is an active load on Tr_6, for realising the differential to single-ended transition.

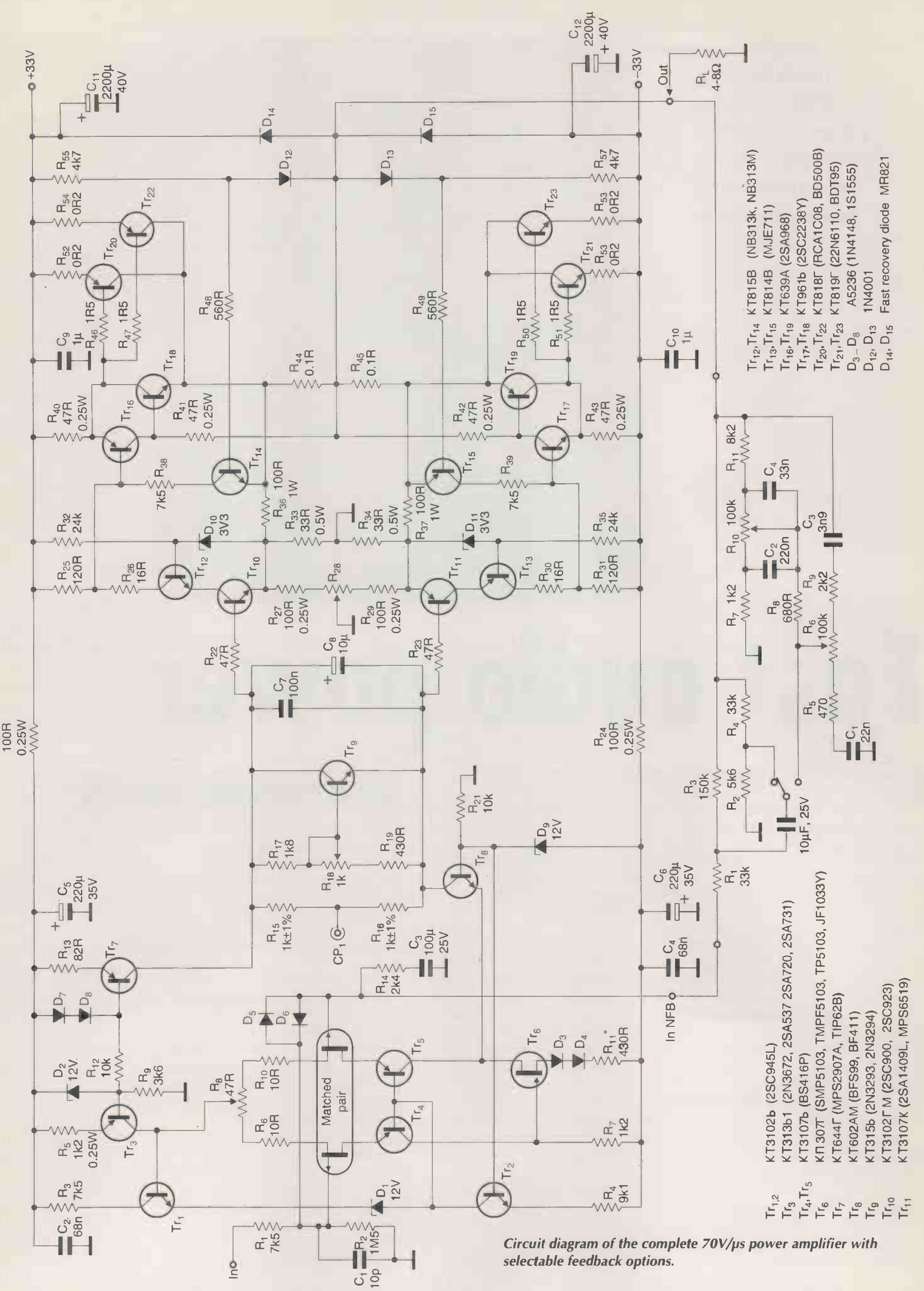
The circuit is simultaneously a stable current generator for the right-hand part of the differential cascade circuit and a current mirror for the second amplification cascade on the transistor Tr_8. This transistor is connected to the common-base circuit and has an active load, transistor Tr_7. Diodes $D_{3,4}$ increase the amplification of Tr_6.

Relative to operation-amplifier circuitry, the precision in forming a single-ended signal from differential one using this circuitry is small. However, the suggested configuration increases speed and, as a consequence, the precision of the input amplifier.

With the aim of increasing amplification precision, the input differential cascade is covered with common-mode signal negative feedback. This is formed by the emitter follower Tr_1 and constant-current generator transistor

Specifications

The amplifier's specifications are,
Output power 90W minimum with 4Ω load.
THD less than 0.03% at 10W output in the frequency range of 20Hz to 20kHz (maximum precision of my distortion meter is 0.03%)
Slew rate greater than 50V/µs.



Circuit diagram of the complete 70V/μs power amplifier with selectable feedback options.

Tr_2 controlling transistors $Tr_{4,5}$ by means of voltage-reference diode D_1. This improves linearity with medium-speed audio signals.

Stabilising the FET pair's drain-source voltage increases the amplification precision under large-signal conditions. It has a favourable effect on the transfer of the treble and bass products.

The gain of two input cascades is about 100; they have a local negative feedback circuit to reduce the amount of overall feedback.

Output stage

The stabilisation circuit around the output transistors' bias is straightforward. Resistors $R_{15,16}$ reduce the amount of the thermal negative feedback and eliminate transient overshoot. They do this by fixing the bias current of the output transistors Tr_{20-23} at 120mA.

The symmetrical output allows the power stage to swing almost to each rail. It contains three amplification cascades.

The first voltage amplifier – transistors $Tr_{10,12}$ – is a cascode. The second is a current amplifier with improved linearity relative to traditional designs. Its transistor, Tr_{16}, has an active linearisation effect on the transistor Tr_{18}. Such cascades can be used for amplifying voltage and current.

To achieve the necessary current drive, the output stage has paralleled devices. A loudspeaker load can have significant reactive product and simple current protection used in even the best amplifiers should not be used.

The output stages have some negative feedback. The first cascade has local current feedback due to the emitter resistor $R_{33}||(R_{27}+0.5R_{28})$. The second cascade has inherent feedback via Tr_{18} collector current to the emitter circuit of Tr_{16}. A further negative-feedback path uses the resistor R_{44} in the output transistor collector circuit for pickup. The distorted output signal is amplified and inverted by the Tr_{18}, which closes this feedback circuit.

The slew rate of the described amplifier with a load of 4Ω reaches 50V/μs without transient overshoot, even when the high/low equaliser is in the negative feedback path. A further benefit is the fact that the products of non-linear distortions created by output stage are not propagated to other cascades via the negative feedback circuit. These are suppressed at source.

The whole output stage is covered with its own general negative feedback through R_{36}, $R_{33}||(R_{27}+0.5R_{28})$, setting voltage gain at 4.7. Trimmer R_{28} permits partitioning of the amount of negative feedback applied to the positive and negative voltage half-waves, minimising parity harmonics.

Transistor Tr_{14} together with the diode D_{12} reduces switching distortion, placing the output cascade, $Tr_{20,22}$ in current generator mode.

At the input of this power audio amplifier, the elimination of the preamplifier requires an increase in voltage gain. In turn this reduces the amount of global feedback needed.

If timbre adjustment is necessary, a passive control at the input or in the general negative feedback circuit of the amplifier is required.

This design is non-inverting, and the high-low equaliser connects to the general negative-feedback circuit. Such a decision allows practically any input resistance to be determined by the value of R_2.

Implementing the amplifier

Transistors of the matched pair should have an I_{DSS} greater than 5mA. Transistor T_6 should have an I_{DSS} greater than 12mA.

Unspecified resistors in the circuit diagram are 0.125W. Resistors $R_{15,16}$ should have 0.1% or better tolerance. If you cannot find such precise resistors, it is possible to select them in pairs with precision of 1Ω within the limits of 980-1020Ω.

Resistors $R_{44,45}$, R_{52-54} are pieces of resistance wire soldered directly to the circuit board. Considering amplification of a real musical signal with peak factor of around three, and taking into account the dissipation of these resistors, such a decision is permissible. During a failure, these resistors will act as fuses.

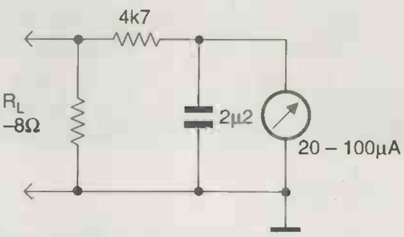
If you want to test the amplifier at full power with a sine wave, the dissipation capability of resistors R_{33-36} should be at least doubled. Capacitors $C_{1,2,4,7}$ are ceramic while C_3 is a non-polarised electrolytic.

Variable resistors in the high-low equaliser should be logarithmic. Each channel of the amplifier can be built on a printed circuit board measuring 120 by 65mm. Capacitors $C_{11,12}$ need to be placed as close as possible to the output devices on each board.

While mounting it is necessary to pay attention to the use of the separate return wires for input and output circuits of the amplifier.

While setting-up and adjusting, it is useful to be able to power up the input and output stages separately by omitting $R_{20,24}$. First the input cascades are checked.

The left-hand leads of R_{22} and R_{23} should be temporarily connected to ground. This permits checking of the input cascades. Next, C_3 is temporarily shunted. Between the points CP_1 and 'In NFB,' connect a 200kΩ resistor. Now set resistor R_8's slider to its middle position.



Using this filter connected to the output, distortion of the amplifier can be trimmed to 0.036% without a distortion meter.

Apply both 30V rails to the input circuit. Resistor R_{11} is adjusted according to the minimum voltage offset in the connection point of resistors R_{NFB} and $R_{15,16}$. Trimmer R_8 allows more precise balancing at the same point.

Checking the output stage

Resistors $R_{20,22-24}$ are put in place and the sliders of R_{18} and R_{28} are set to their top and middle positions respectively. At first turn-on, it is advisable to use a power supply with its current limiting set to approximately 150mA.

If there are no errors in the circuit, current consumed by the output circuit is minimal. Trimmer R_{18} is used to set the output stage bias current to a total of 120mA. Resistor R_8 balances the whole amplifier.

Remove the bypass around C_3.

Non-linear distortions are minimised via R_{28} by measuring with a distortion meter. This minimising of even-signal output harmonics is at the expense of equal gain setting.

When the input is a sine wave, the amplifier output will comprise the sine wave voltage and second harmonic. This harmonic is proportional to the input signal's amplitude squared and also to higher-order harmonics.

During setting up, a low-pass filter and meter as shown can be used for indicating minimal nonlinear distortions. Linearisation is tuned via R_{28} by measuring fundamental voltage at the amplifier's output with an input sine wave between 5 and 8kHz and with a level equal to 0.7 of maximum.

Such linearisation gives good precision. Initially it should be possible to achieve 0.08% THD. After non-linearity is cancelled by means of the microammeter, distortion should decrease to 0.036%. Further minimisation using a distortion meter enables distortion to be reduced to 0.03%. ■

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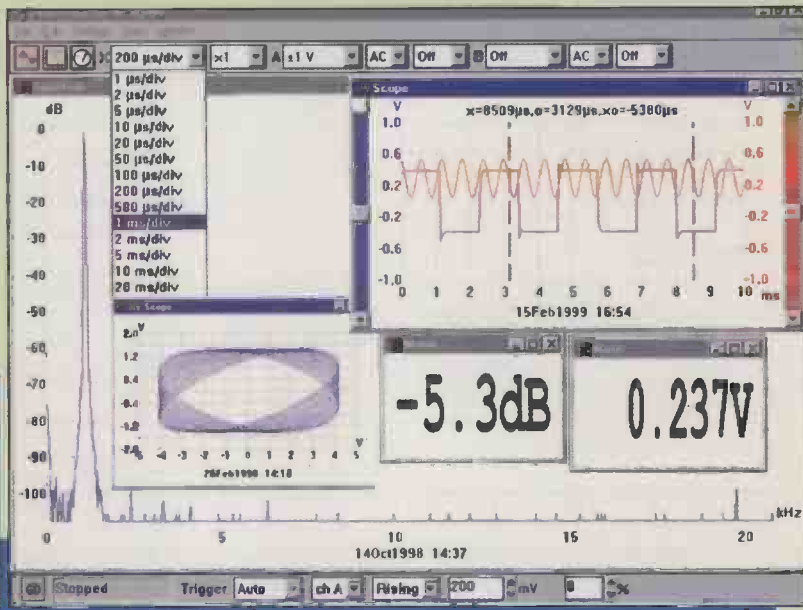

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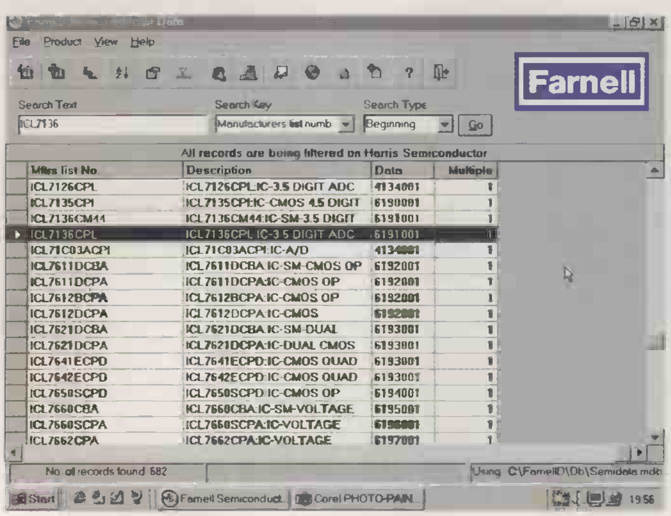

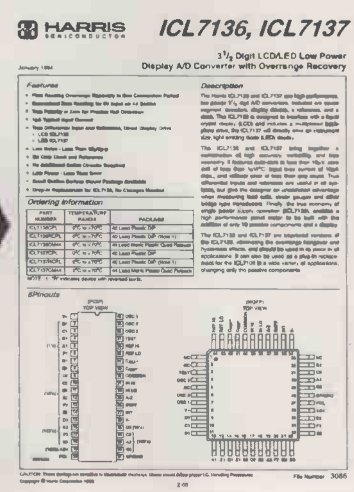

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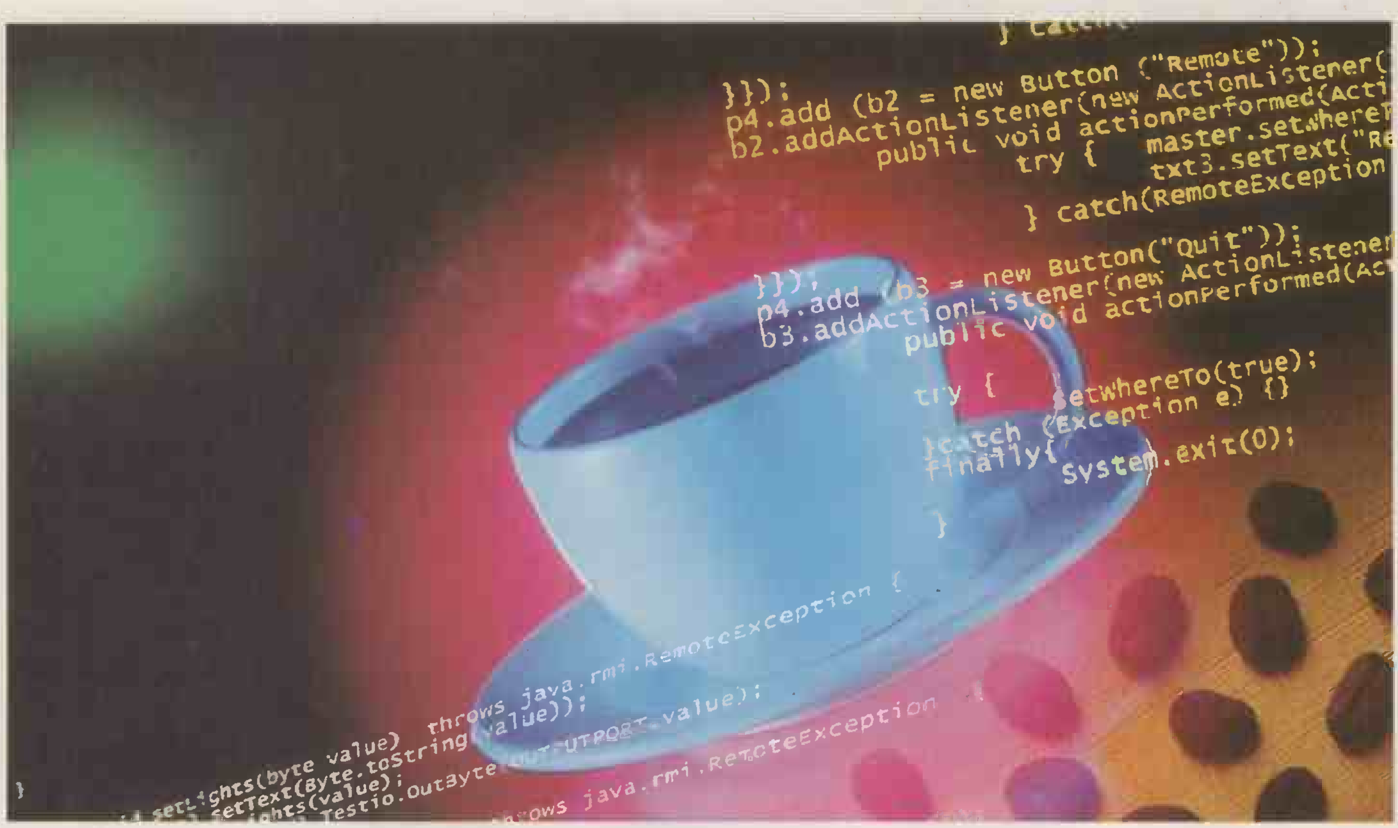


Interfacing with Java

Java prides itself on platform neutrality and portability. But what about computer interfacing with non-standard hardware? Les Hughes investigates.

Java technology was originally conceived as a simple means to power embedded devices, primarily set-top boxes – television decoders and such. However, the rise of the Internet saw Java drift off course somewhat.

Recent developments such as Embedded Java and Personal Java witness a shift back towards Java's roots. These products differ from the mainstream Java development kit in that they often require support from a real-time operating system (RTOS) of some kind. For example, WindRiver Systems was one of the first to offer Embedded Java on a true embedded platform – PowerPC, MIPS or Intel – by porting a JVM to their VxWorks RTOS.

This is fine if you have several thousand pounds to spend on development systems and a real-time operating system, but what about the original free JDK and a common PC? Can't we somehow bend Java to our will and accomplish some standard interfacing tasks? Of course we can.

Before I look at the role Java can play in interfacing, I'll briefly discuss the roles operating systems and device drivers have in allowing a program access to hardware devices.

Living with an operating system

Modern operating systems prohibit direct hardware access by user programs. Your program makes service requests of the operating system – also known as the Kernel – which then proceeds to talk to the hardware through a device driver.

Instead of accessing hardware directly with a call such as inportb(), control is transferred to the operating system so that it can service your requirements, **Fig. 1**. This approach protects the computer from badly behaved programs and adds to the overall robustness of the operating system. The downside is that every custom device needs a custom device driver and for many operating systems, writing device drivers is no simple task, even for an advanced programmer.

However, all is not lost. Some operating systems developers – notably those working on Linux – actively encourage wide involvement in creating drivers for yet-to-be supported hardware. All of the required tools and several dozen production-quality drivers, which can be used as examples, are shipped with the OS as standard.

Also, it's a safe bet that if you're looking at doing something special with a piece of hardware on a Linux box, someone somewhere has already tried something similar and written a driver. The Linux Lab Project brings together a large quantity of these drivers and is worth a visit before reaching for your compiler.

Beyond Linux, 'generic' drivers are available for some operating systems. These drivers are not targeted at a particular expansion card; they simply provide indiscriminate access to the computer's hardware. While nowhere near robust enough for production quality systems, the use of a simple generic driver with a custom prototype board can give more than satisfactory results in an experimental environment.

A word of warning though: a generic driver is just that. Remember that they allow unrestricted access to memory and hardware, sacrificing the protection provided by the OS. It is incredibly easy to crash a system when experimenting with a generic driver. It is also theoretically possible to corrupt disks, damage monitors and inflict no end of suffering upon your poor PC if you write data into the wrong locations.

With reasonable care though, a generic driver provides a simple and safe solution to the 'unsupported hardware' problem.

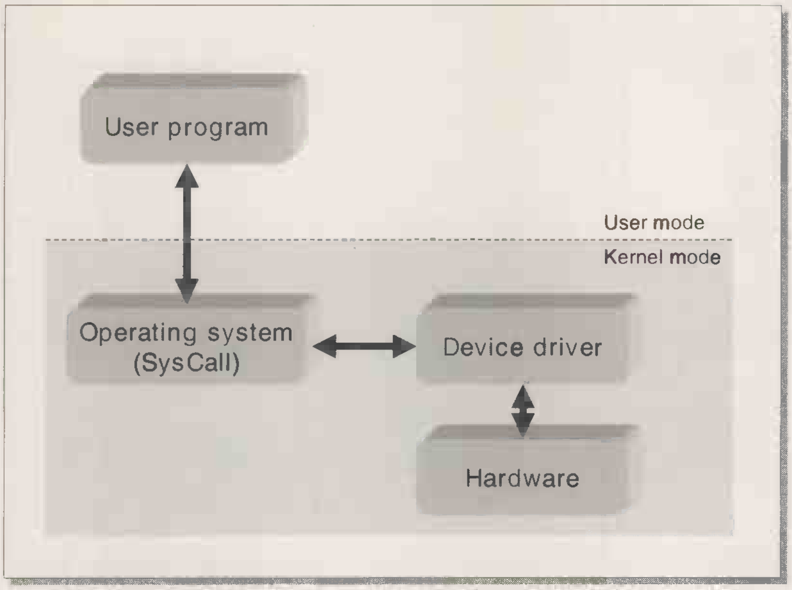


Fig. 1. Instead of accessing hardware directly with a call such as inportb(), control is transferred to the operating system so that it can service your requirements.

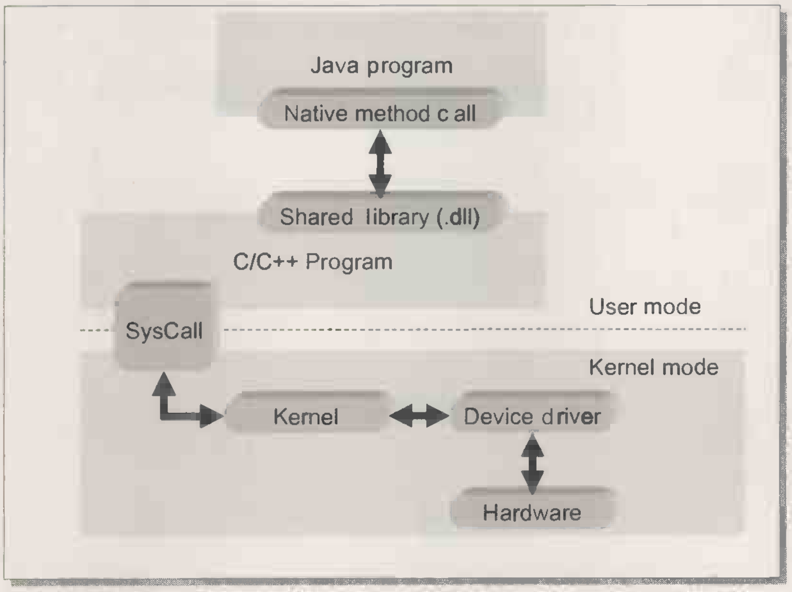


Fig. 2. The library acts as a 'wrapper' that converts Java 'method' calls into the corresponding device driver calls.

Talking to the natives

Having touched on some of the aspects of working with a modern multi-tasking, multi-user operating system, you could be forgiven for thinking that things can only get easier. Unfortunately, once you try to break free from the confines of the Java virtual machine, you encounter a number of vendor imposed difficulties.

In order to 'hook' into a device driver you need to run native code – code compiled specifically for the target platform. This code is written in C (or C++) and compiled into a shared library (.dll or .so) with a tool such as Visual Studio or GNU gcc, depending upon the platform.

EEPort.java notes

You may be wondering, "Why have an open and close method that doesn't really do anything?" A perfectly valid point. However, if you were to move your Java code to Linux for example, then you would have to actually open the device to gain access – which is not the case with the generic win32 driver. Of course, you would have to re-write your native code as well as modifying EEPort's implementation of open and close at that time. But by defining the open/close interface now, you minimise the effects of moving to another platform later.

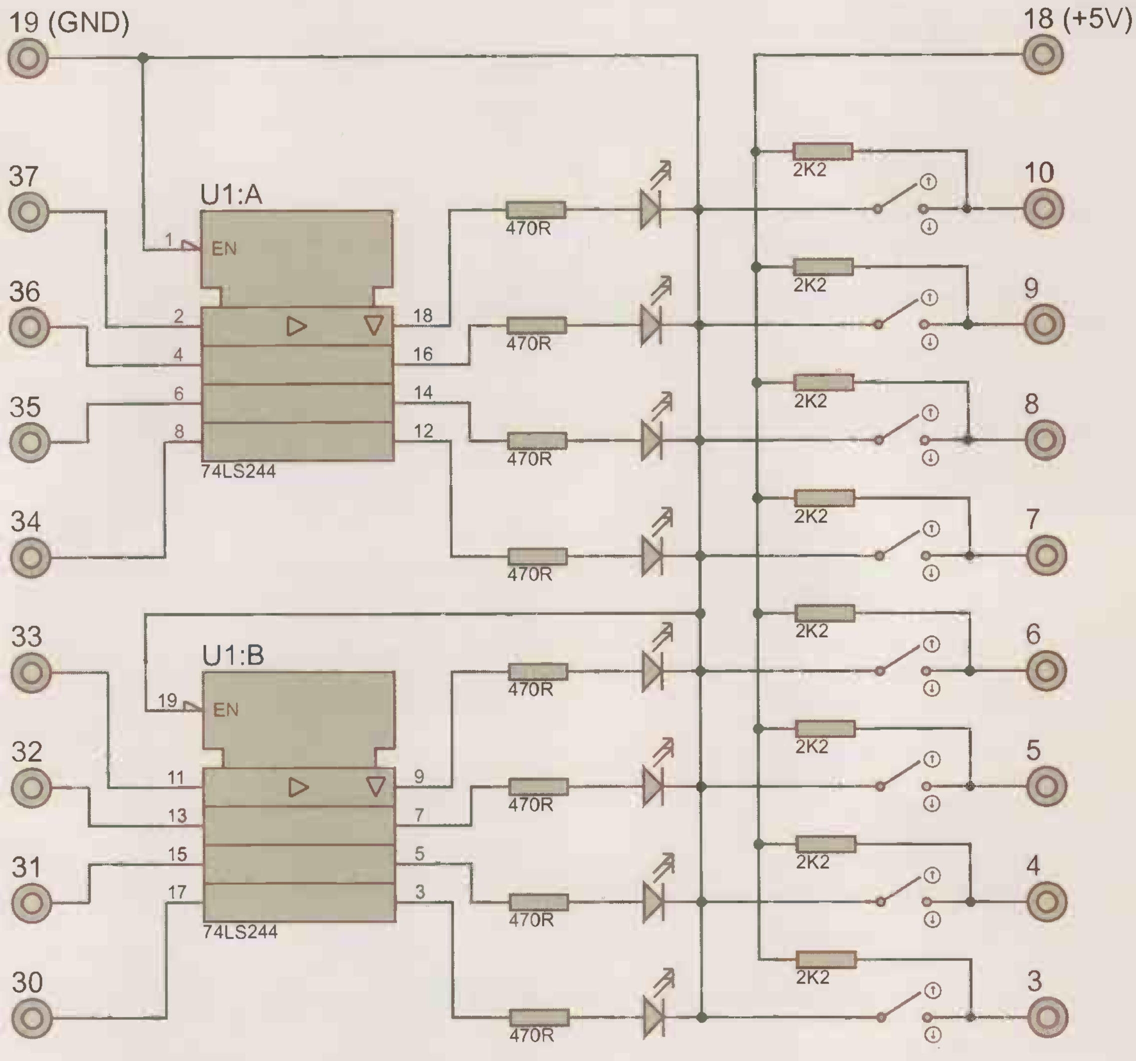


Fig. 3. Simple lights and switches circuit for interfacing to two ports of the 8255 card.

This library acts as a 'wrapper' that converts Java 'method' calls into the corresponding device driver calls, Fig. 2. Different platforms require different device driver calls and a different library.

Unfortunately, these 'hooks' from the Java virtual machine into native C/C++ code come in different, incompatible flavours depending upon the Java product used.

How EEPortTest.java works

Most of the code is spent in setting up the graphical user interface. Lines of particular interest are 27-9 which create three ports, A, B and a configuration port and lines 73-78 that actually read and write data. Notice on line 73 how we 'message' inputportA and ask it to read some data for us. Line 78 shows a similar write action, this time on outputportB.

As happens all too often in computing we find that the world is divided into two camps; Microsoft's JDirect/RNI system and everyone else's Java Native Interface API. JDirect is only available on Win32 platforms giving simple access to the Win32 API. JNI on the other hand should be available wherever you find a Java virtual machine.

Originally, Microsoft decided that its way was best and declined to implement JNI. A court ruling late last year ordered Microsoft to include, amongst other things, JNI and an updated JVM is available from their website.

JNI is 'binary compatible' across platforms and Java virtual machines. Your Java code for interfacing on a Sun *shouldn't* need recompiling on a PC: you just need to supply the correct library file. Contrasting this is the fact that code written to take advantage of JDirect's simplicity will never run on anything other than a Win32 box. For this reason, I only consider JNI from here.

As with most aspects of the Java Technology, JNI could warrant a whole series of books and articles itself. Since this article mainly concerns wrapping Java methods into native API calls, I won't delve too deeply into the JNI. A further source of JNI information is listed in the references.

The development system

Obviously, interfacing is hardware specific and you need to choose some hardware. Omega Engineering produces an 8255 based i/o card that, unlike some others, includes support for interrupt driven i/o.

A Linux driver is available to take advantage of this feature. However, I will concentrate on using this hardware without interrupt support, on Win32 with a generic port driver.

In order to generate some input and to show some output, a test circuit will be required. Perhaps the simplest – and most widespread – is the 'lights and switches' style box; an array of eight LEDs and eight switches, **Fig. 3**. The 8255 card mentioned above provides three 8-bit ports but you only need two for what's described here; PortA for input and PortB for output.

A 74LS245 octal buffer is used to protect the outputs of the i/o card and pull-up resistors ensure correct logic levels on the inputs.

For Win32 development you will need a copy of JDK > 1.1.5, which is free from java.sun.com. You will also need a means of producing a Windows DLL, a suitable interface card and the DriverLINX Port i/o Driver for the test circuit. There's more on the driver and DLL below.

Some of these tools and utilities are available from my website, whose address is given later. Once you have obtained the hardware and software, you should follow the supplied instructions regarding installation and configuration. In particular, you should read the README file that comes with the DriverLINX Port i/o Driver.

A simple example

Enough theory. Now I will show how to create a simple application to demonstrate some of the principles involved in interfacing with Java.

Assuming you have installed all of the required hardware and software – drivers, compilers, etc. – you first need to plan your design. Java is an object-oriented language and you should be creating software 'things' if you want to exploit the power of the language fully.

For our model, an obvious 'thing' is a representation of the Port itself. Your software Port will be responsible for interacting with the OS via JNI, and will provide you with the necessary port 'behaviours'; read, write, open and close with perhaps some kind of control behaviour.

Other client objects – those that require the services of a port – aren't interested in the gory details, they just want to read and write some data. Most probably, they also won't care about others who are using the port. Your port thing should therefore marshal port accesses, locking the resource so that only one part of the program may use the resource – again, an important task, **Fig. 4**.

Taking these ideas further, perhaps it would be a good idea to create a 'PortManager' of some kind? This isn't really necessary for your first attempts at interfacing, but for a larger system a Manager would be made responsible for allocating ports to client objects, etc. For the moment though, it is best to put these management and access ideas to one side and remember to manage the ports yourself.

The Java side of the port doesn't really have to do much for the time being. You need to define the 'services' it provides and to simply map these into our native calls. Later, you could expand each of these services, keeping the names the same but enhancing what each one does. This iterative approach is often used in object-oriented development – you can change the implementation as long as you leave the interfaces alone.

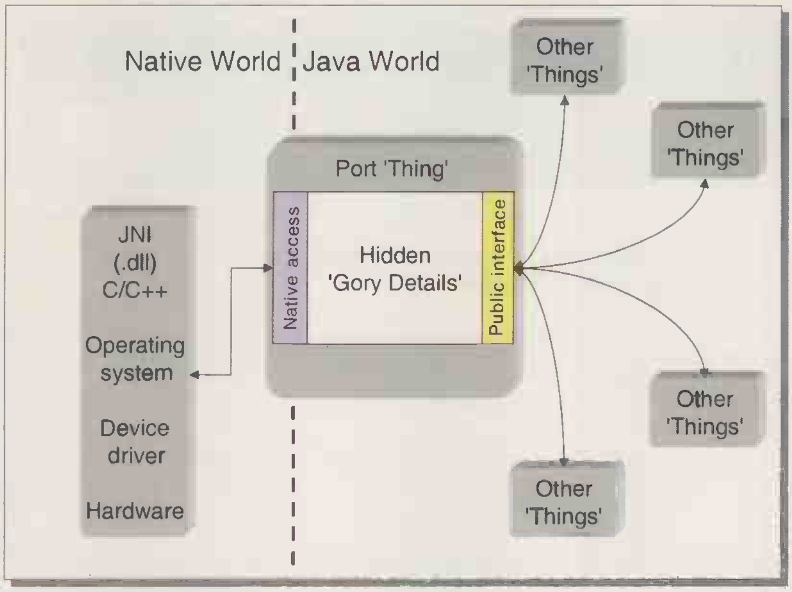


Fig. 4. Your port 'thing' should marshal port accesses, locking the resource so that only one part of the program may use the resource.

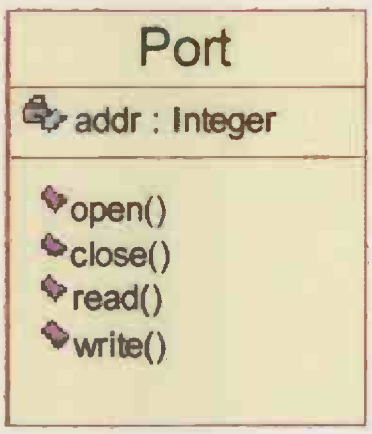


Fig. 5. Class diagram for a port, with four methods – open, close, read, write – and a privately stored address field.

List 1. Defining an i/o port in Java.

```
public class EEPort{

static {
    System.loadLibrary("javaio");
}
    int addr;
    boolean isOpen;

    public EEPort(int addr) {
        isOpen = false;
        this.addr = addr;
    }

    public void open() {
        isOpen = true;
    }
    public void close() {
        isOpen = false;
    }
    public byte read() {
        if(isOpen) {
            return _read(addr);
        } else {
            return 0;
        }
    }
    public void write(byte data) {
        if(isOpen) {
            _write(addr, data);
        }
    }
    public void setDebug(boolean flag) {
        _setDebug(flag);
    }
    private native void _write(int addr, byte data);
    private native byte _read(int addr);
    private native void _setDebug(boolean flag);

}
```

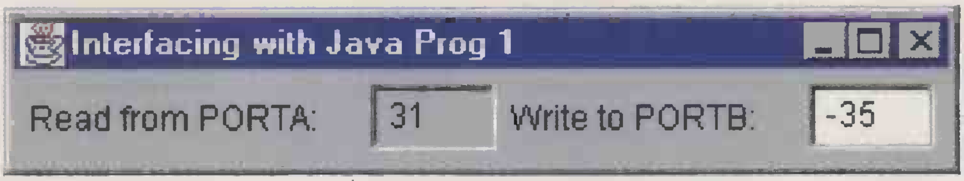


Fig. 6. List 2 in operation. This application reads port A every 100ms, displaying the result in a box.

List 2. Simple application that reads the value on PortA every 100ms, displaying results in a text box.

```
import java.awt.*;
import java.awt.event.*;
public class EEPortTest extends Frame implements Runnable {
        TextField   portAText;
        TextField   portBText;

        Label       portALabel;
        Label       portBLabel;
        EEPort      inputportA;
        EEPort      outputportB;
        EEPort      configport;
        Thread      runner;
        static final byte controlword = (byte)0x99;
        static final int PORTA              = 0x300;
        static final int PORTB              = 0x301;
        static final int PORTC              = 0x302;
        static final int CONFIG             = 0x303;
    public EEPortTest() {
        super("Interfacing with Java Prog 1");
        inputportA  =   new EEPort(PORTA);
        outputportB =   new EEPort(PORTB);
        configport  =   new EEPort(CONFIG);
        configport.open();
        configport.write(controlword);
        configport.close();
        inputportA.open();
        outputportB.open();
        setLayout(new FlowLayout());
        portAText = new TextField("0",3);
        portAText.setEditable(false);
        portBText = new TextField("0",3);
        portALabel = new Label("Read from PORTA:");
        portBLabel = new Label("Write to PORTB:");
        add(portALabel);
        add(portAText);
        add(portBLabel);
        add(portBText);
        (runner = new Thread(this)).start();
        this.addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent w) {
                System.exit(0);
            }});
        this.pack();
        this.setVisible(true);
    }
    public void run() {
        while(true) {
        try {
            byte data = inputportA.read();
            String sometext = Byte.toString(data);
            portAText.setText(sometext);
            data = Byte.parseByte(portBText.getText());
            outputportB.write(data);
            Thread.currentThread().sleep(100);
        } catch(InterruptedException expt) {
        } catch(NumberFormatException nfexpt) {}
        }
    }
    public static void main(String args[]) {
        EEPortTest porttest = new EEPortTest();
    }
}
```

Figure 5 shows a class diagram for your port, with four methods – open, close, read, write – and a privately stored address field. The class operates thus; an object creates a port to write to, telling it the address it's interested in. The port stores this for future reference. The client object then opens the port, reads and writes data from the previously announced address and finally closes the port.

Implementing a port

Let's implement the port in Java, **List 1**. First, define the class name (EEPort). Your EEPort class needs to load your compiled C/C++ library before it can do anything. This is achieved using the loadLibrary method.

You then define the constructor for your class. This piece of code is executed whenever another object creates a port to work with. The constructor accepts an integer representing an address for you to work with. The constructor also sets the isOpen flag to false, indicating that the port is closed.

Next, define your methods. Open and close simply change the isOpen flag. Read and write check the isOpen flag. If the port is currently open, perform the required action via a native call (_read and _write) shown at the end of the listing.

These native method calls are the actual hooks out into the real world. Notice how they have no body. The actual implementation for these methods takes place in our C/C++ library. To facilitate debugging, a setDebug method is included that causes the native code to generate some helpful messages.

Working through a typical scenario, imagine a client object creates and opens a port. It then calls read which in turn calls _read. This causes some native C/C++ code to execute that finally accesses the hardware. The data read from the hardware bubbles up through the various called methods and ends up back at our application.

Compiling

Assuming you are using the Sun JDK, you would compile EEPort.java using the command:

C:\> **javac EEPort.java**

This should produce EEPort.class. Now we have our port, let's create a simple application showing how we use it before we look at the platform specific C/C++ code.

List 2 is a simple application that reads the value on PortA of the 8255 every 100ms, displaying this data in a text box. The application also reads the value entered in a second text box and sends it to PortB, to appear on the LEDs. A screen shot of the application in action appears in **Fig. 6**. Again, use javac to compile:

C:\> javac EEPortTest.java

which should result in EEPortTest.class.

Going native

The last piece in the jigsaw is the native code; i.e. code written in C acting as a simple wrapper. You can now complete this jigsaw by creating your library .dll.

The links that connect Java to C are the JNI native methods. These are defined in our Java file but our C compiler knows nothing of Java declarations. Somehow we have to translate our native method declarations into C function prototypes. Fortunately, Sun has kindly provided a tool to do this for us, as part of the Java Development Kit.

The javah program scans class files extracting the required information concerning JNI calls. It then assembles this data into a C header file that defines the necessary function prototypes ready for you to implement. To generate a header file from your EEPort.class file, run the following:

C:\> javah –jni EEPort

This should produce EEPort.h that defines three functions corresponding to read, write and debug methods. These prototypes are somewhat confusing in nature due to the amount of information that needs to be passed outside of the JVM into native land. You won't use most of this data and you can ignore the various pointers, etc. passed to you.

A more advanced program could call back into the Java virtual machine, invoke a Java method from C or even create another JVM. All that is needed here is to send and receive some data. The completed library program to accomplish this is shown in **List 3**.

The first few lines import standard library headers as well as the header generated above and the header supplied with the port driver. The generic driver exports the functions DlPortReadUchar and DlPortWriteUchar for reading and

List 3. This program calls back into the Java virtual machine and invokes a Java method from C.

```
#include <jni.h>
#include <windows.h>
#include <conio.h>
#include "Dlportio.h"
#include "EEPort.h"
#define INP DlPortReadPortUchar
#define OUTP DlPortWritePortUchar
BOOL debug;
JNIEXPORT void JNICALL Java_EEPort__1setDebug
  (JNIEnv * env, jobject obj , jboolean flag) {
        debug = flag;
}
JNIEXPORT void JNICALL Java_EEPort__1write(JNIEnv * env, jobject obj, jint
portaddr, jbyte outval)
{
    if (debug) {
        printf("values are port=%d; value=%d\n", portaddr, outval);
        printf("About to try to write to port\n");
    }
        OUTP(portaddr, outval);
        if (debug)
        printf("writing to port done\n");
}
JNIEXPORT jbyte JNICALL Java_EEPort__1read(JNIEnv * env, jobject obj, jint
portaddr)
{
        jbyte inval;
        if (debug) printf("About to read byte from port\n");
        inval = (jbyte)INP(portaddr);
        if (debug) printf("byte read, value is %d\n", inval);
        return(inval);
}
```

List 4. A datagram transmitter. This class fires out a series of Internet protocol datagrams; packets of data based on the Unreliable Datagram Protocol.

```
import java.net.*;
import java.io.*;
public class DgramTx implements Runnable {
    private App ip;
    private InetAddress inet;
    DatagramSocket sock;
    private Thread runner;
    public DgramTx(App ip) throws Exception {
        this.ip = ip;
        inet = null;
        sock = new DatagramSocket();
        (runner = new Thread(this)).start();
    }
public void run() {
    while(true) {
        if(inet != null) {
                byte[] buf = new byte[32];
         buf[0] = ip.read();
                DatagramPacket dg = new DatagramPacket(buf, buf.length, inet,
12345);
                try {
                 sock.send(dg);
                }catch(IOException i) {}
        }
        try{
         Thread.currentThread().sleep(100);
        }catch(InterruptedException ex) {}
    }
}
public void setWhereTo(InetAddress inet) {
    this.inet = inet;
}
}
```

List 6. This, the main application, creates the GUI, the two i/o ports and the networking objects and joins them all together. It also intercepts read and write operations from DgramTX & DgramRX so as to be able to display information on the GUI.

```
import java.net.*;
import java.awt.*;
import java.awt.event.*;
public class App extends Frame {
    private TextField theHost;
    private TextField theOutput;
    private TextField theInput;
    private Button setHost;
    EEPort inp;
    EEPort oup;
    DgramTx tx;
    DgramRx rx;
    public App() throws Exception {
        super("Datagram Application");
        //COnfigure the 8255 card
        EEPort ctl = new EEPort(0x303);
        ctl.open();
        ctl.write((byte)0x99);
        ctl.close();
        ctl = null;
        //Create our in and out ports
        inp = new EEPort(0x300);
        oup = new EEPort(0x301);
        inp.open();
        oup.open();
        //Create our Network TX
        tx = new DgramTx(this);
        //Create our Network RX
        rx = new DgramRx(this);
        //Build our GUI
        setHost = new Button("Set Host");
        theHost = new TextField(20);
        theOutput = new TextField(5);
        theInput = new TextField(5);
        setLayout(new FlowLayout());
        //Add Components to form GUI
        add(new Label("RxD from Network"));
        add(theOutput);
        add(new Label("TxD to the Network"));
        add(theInput);
        add(new Label("Enter Remote Hostname"));
        add(theHost);
        add(setHost);
        //Add an actionlistener monitoring
        //the setHost button
        setHost.addActionListener(new ActionListener(){
            public void actionPerformed(ActionEvent a) {
                try{
                    tx.setWhereTo(InetAddress.getByName(theHost.getText()));
                }catch(UnknownHostException ex) {
                    theHost.selectAll();
                    Toolkit.getDefaultToolkit().beep();
                }
            }});

        //Add a listener to close the App
        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent w) {
                System.exit(0);
            }
        });
        pack();
        setVisible(true);
    }
    //A method to write Data to the port
    //and to the textfield
    public void write(byte data) {
        theOutput.setText(Byte.toString(data));
        oup.write(data);
    }
    //A method to read Data from the port
    //and show in the textfield
    public byte read() {
        byte data;
        data = inp.read();
        theInput.setText(Byte.toString(data));
        return data;
    }
    //The main method
    public static void main(String args[]) throws Exception{
        App theApp = new App();
    }
}
```

writing. You alias these to INP and OUTP for short.

The setDebug function appears next, setting the BOOL defined on the previous line to true or false. Notice that you only use the last parameter passed into the function, jboolean flag.

You will also notice how the names for each function (read, write and debug) contain information as to where the Java method was defined. For example, the _read method appears as Java_EEPort__1read in the native code.

One final thing is the way in which Java data types are prefixed with 'j'; jbyte, jint, etc. This helps you keep Java types and C types separate.

The read and write functions follow a similar format to the setDebug function. They do not need to access back into the JVM, or reference the object that called them and so they ignore the first two parameters. In fact, the read function only uses the jint portaddr value returning a jbyte and the write function uses a jint for the port address and a jbyte for data.

This C code is compiled into a Windows .dll – in this case javaio.dll - using Visual Studio or similar. If you are building your own .dll instead of downloading the precompiled version, you must remember to include your Java distribution's 'include' directory with your project (for jni.h) and to link against dlport.lib, which is part of the port driver package.

Exact instructions vary from compiler to compiler, so you should refer to your manuals. Once you have produced your .dll, you should copy it into the same directory as EEPort.class This way, the JVM will be able to find your native library when it needs to.

Running the test application

By now you should have EEPort.class, EEPortTest.class and javaio.dll in one directory. Start the test application:

C:\> java EEPortTest

You should see a window similar to that in **Fig. 6**. Enter some data into the right-hand text box and watch the lights change. Now change the switches and observe the left-hand text box reflect these changes.

Moving on

One of the nice things about Java is the simplicity with which otherwise complicated tasks can be accomplished. As a slightly more advanced

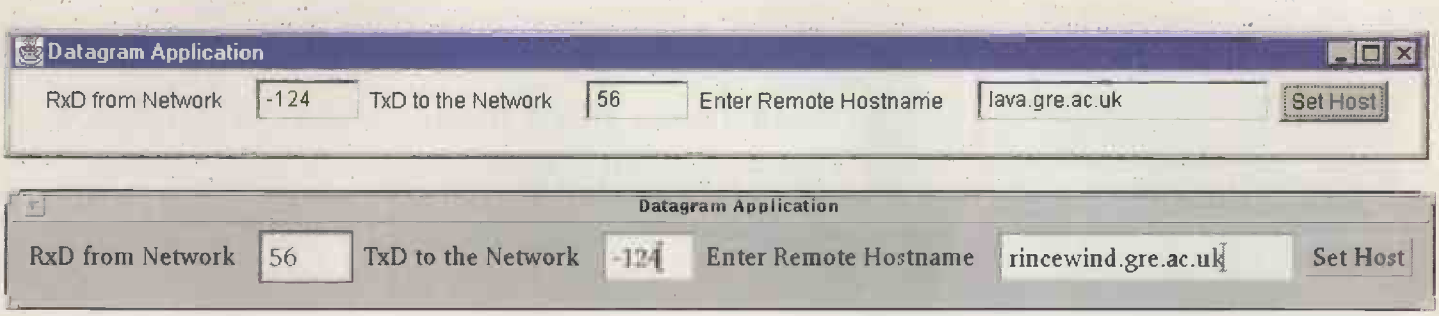


Fig. 7. Screen shots taken while list 6 – the networking demonstration application – is running.

example, a networked set of lights'n'switches can be easily constructed now that you have your i/o infrastructure.

The code shown in **List 4** represents a datagram transmitter. This class fires out a series of Internet protocol datagrams; packets of data based on the Unreliable Datagram Protocol (UDP). UDP provides for connectionless transmission where delivery is not guaranteed. However, since you are just experimenting with networking, this protocol is more than adequate.

The DgramTX class reads data from our input port every 100ms. This data is sent across the network in a UDP datagram, to be received by a DgramRX, **List 5**.

The DgramRX listens out for incoming datagrams, unpacking data from those it receives and sends this data to the output port. These two classes form the heart of our transport system.

Joining everything up is a simple class named App – the main application, **List 6**. This class creates the GUI, the two i/o ports and the networking objects and joins them all together. It also intercepts read and write operations from DgramTX & DgramRX so as to be able to display information on the GUI.

A screenshot of the running application is shown in **Fig 7**, performing reads and writes from an NT machine to a Sun workstation – all with the same basic Java code.

In order to make use of these classes, you will need a friend with an interface card, a lights'n'switches box and Internet access. Simply get on line, enter the host name or IP address of the other machine in the GUI and start sending data.

Your switch settings appear on their lights and *vice versa*. You can also enter your machine's name or IP address that will cause your LEDs to reflect the setting on your switches.

List 5. DgramRX listens out for incoming datagrams, unpacking data from those it receives and sends this data to the output port.

```
import java.net.*;
public class DgramRx implements Runnable {
    private App op;
    private DatagramSocket sock;
    private Thread runner;
    public DgramRx(App op) throws Exception {
        this.op = op;
        sock = new DatagramSocket(12345);

        (runner = new Thread(this)).start();
    }
    public void run() {
        while(true) {
            try {
                byte buf[] = new byte[32];
                DatagramPacket dg = new DatagramPacket(buf,
buf.length);
                sock.receive(dg);
                buf = dg.getData();
                op.write(buf[0]);
            }catch(Exception e) {
                    e.printStackTrace();
            }
        }
    }
}
```

In summary

To summarise, interfacing in Java is achieved in a similar manner to any other language, except for the complication of having to join platform independent Java with native C code. Once this task is complete, the generated .dll and .class files allow 'invisible' hardware access permitting you to exploit most of Java's advanced features; networking, multiple threads, object serialisation, etc. ■

Biography

Formerly a Senior Lecturer in Software Engineering with the University of Greenwich, Les is now with Parallax Solutions (www.parallax.co.uk) working in the area of object technology and, of course, Java. He is a Sun Certified Java programmer and has worked on a number of JNI related projects; Internet controlled hardware, object storage FPGAs and a rather nice networked coffee machine.

Need more information?

The Linux Lab Project http://www.llp.fu-berlin.de/
Microsoft's Java pages http://www.microsoft.com/java/
Omega Engineering (8255 card) http://www.omega.co.uk/uk/index.html
DLPort Driver from Scientific Software Tools http://www.sstnet.com/
JNI information http://java.sun.com/products/jdk/1.1/docs.html
Software mentioned in the article (javaio.dll etc) can be found at http://www.parallax.co.uk/~leslieh/index.html

Has Tina's third incarnation – Tina Pro – been worth waiting for? Rod Cooper investigates.

The route to simulation III

Review subjects

The first review covered ***Electronics Workbench*** version 5.12, whose maker is IIT Ltd of Canada. Workbench's UK supplier is Adept Scientific plc, tel 01462 480055. ***Electronic Workbench***'s price is £199.

Rod looked at ***CircuitMaker*** in the August issue. This £199 package is made by MicroCode in the US and supplied by Labvolt in the UK, tel. 01480 300695. Subsequent reviews will cover Labcenter's ***Lisa***, which is part of *Proteus IV*, and ***Pulsar and Analyser*** from Number One Systems, which are modules from the *Easy PC* package.

Tina is a relative newcomer to the UK. It was first reviewed in *Electronics World* in the September 1996 issue by Clive Ousby. I recommend that you take a look at Clive's review to get a broader view of the program.

The original Tina program was upgraded to Tina Plus, and it has now been further developed into the new Tina Pro. The main differences in Tina Pro include a change to 32-bit operation, a much improved schematic drawing program, an expanded model library, and several extra analyses. This is a big leap forward by any standard. The latest version 5.21 of this new program has become a useful wide-ranging general-purpose program.

The minimum system requirements are a 486DX, 16Mbyte of RAM, at least 15Mbyte of disk space to install, and Windows 95 or 98 or NT4.0. There is no Windows 3.1 version.

The copy of Tina Pro provided for review was on a CD, and installation was straightforward. Security is a little more complex than with other programs though. A registration number is provided with the CD.

The owner has to contact the supplier or e-mail DesignSoft and exchange this number for a unique security number. This can take a while, but the package can be used up to 15 times without the security key, at which point the program will not run again until the number is entered.

The security key is specific not only to one computer but also the directory it is installed in, so the program cannot be moved. As an alternative, some versions are dongled. In practice, using e-mail, the security key took just three days to arrive.

Documentation

The user manual has been rewritten, and now has a less academic approach than previous versions. It follows the current trend of many Windows applications in being a small volume, without an index or glossary, giving just the bare essentials. More reliance is made on the program's Help files. Of the programs reviewed, Tina has the least reading matter.

The program help files hierarchy has considerable depth, but the files themselves are sometimes brief. There is a set of tutorials which are more helpful – especially for those new to using the Tina system. These run either from the program CD, when there are 20 tutorials available, or alternatively, they can be accessed from the Help menu, in which case you get 25.

The advantage of accessing them from

the Help menu is that you can refer to a specific tutorial during work on your circuit, perhaps to refresh your memory on a particular topic, then flip straight back to the circuit. To do this, the tutorials need to be transferred to the hard disk during the main program installation. Although they take up 15Mbyte, it is well worth the hard disk space.

There is also assistance in the form of a self-running demonstrator CD. I did not find the manual, Help files, or the demonstrator very useful individually. When they are combined with the tutorials though, it was possible to get up and running fairly quickly, especially as the program is largely intuitive.

Schematic drawing

Symbols are presented in generic form in a series of twelve pre-stocked symbol parts-bins. They include a set of virtual instruments, probes, and measuring tools, so Tina is fine for on-screen experimentation.

It is possible to add to and modify the content of these parts-bins via an editing tool. The symbol library is backed by a library of 10 000 component models – a doubling over the previous version.

Mouse operation in Tina is straightforward; click left to commence, click right to finish, click left to select an existing symbol and right to edit via a sub-menu. There are no complicated left-plus-right routines to memorise. This system is carried over into the simulations.

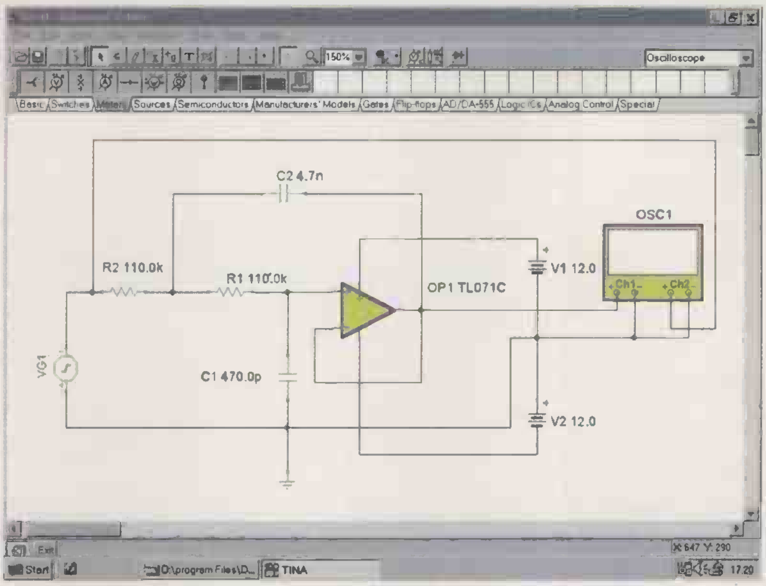
Wiring up

The wiring up part of the schematic editor is a big improvement on previous versions. It is now possible to wire up symbols quickly and easily, and just as quickly delete them. To wire up you can either click right and choose this function, or simply move the cursor to a symbol terminal, when it changes to a drawing pen, and off you go.

You can choose whether to wire manually or automatically. Autowiring is not like the systems found in other programs, but is more of an assisted manual method. Both systems were pleasant to use.

Wires under construction can be deleted by reversing the track, and whole wires can now be deleted by selecting them with the right mouse button and picking 'delete'. Previously they had to be deleted section-by-section. However mistakes – wires ending in space for example – are not automatically deleted.

The schematic drawing is orthogonal. It is possible to move the symbol



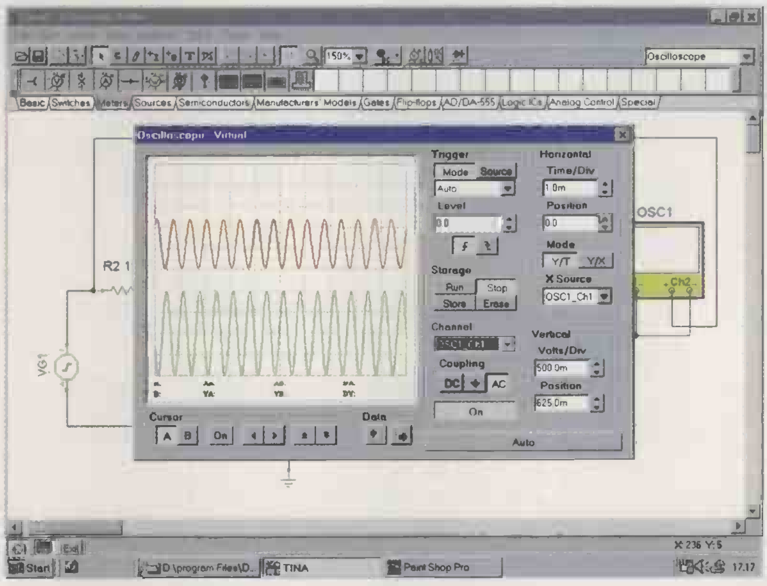


Fig. 1. A Tina schematic, showing how the virtual instruments are wired into circuit, much like Electronic Workbench, top, and the virtual oscilloscope expanded to show the controls, left.

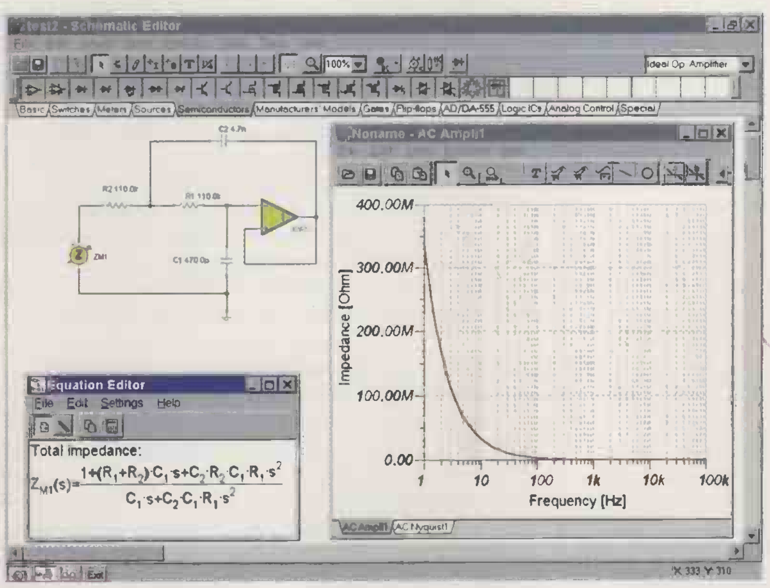


Fig. 2. Input impedance graph, and symbolic analysis of input impedance. A semi-symbolic form, i.e. with values inserted, can also be obtained.

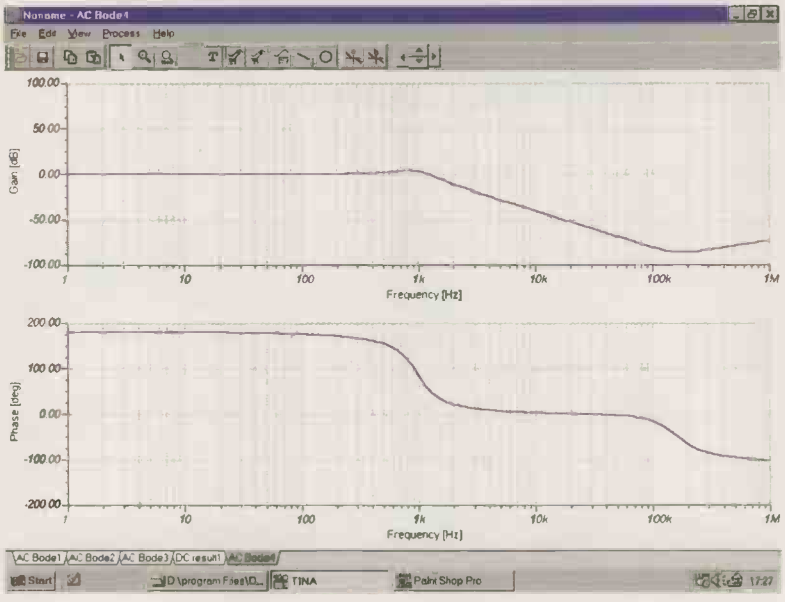


Fig. 3. Analysis of gain and phase, expanded to run full-screen for easier measurement.

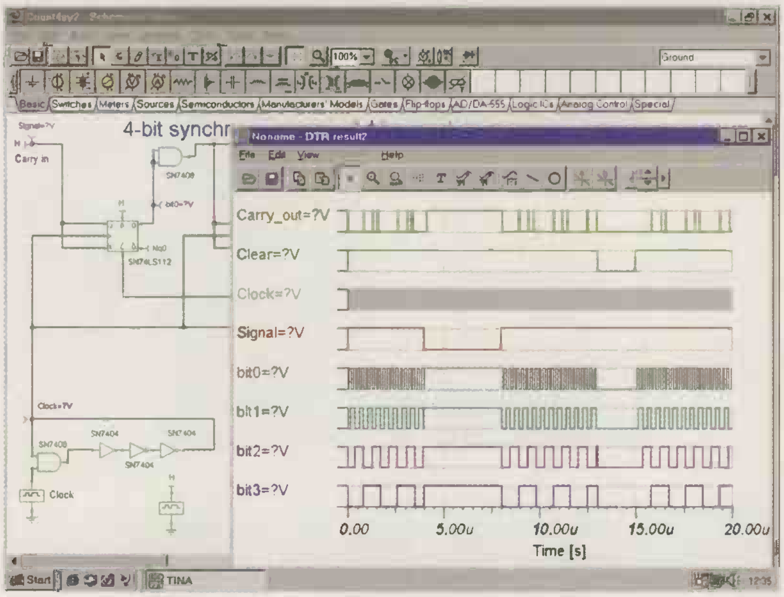


Fig. 4. Typical digital timing chart of a counter circuit with glitch control set at 60%.

text around to make neat diagrams. Junction dots are automatically inserted and symbol annotation is carried out as you go along.

Wiring is assisted by a dot grid and a good but non-adjustable snap-to function makes for a good degree of reliability in net-list generation. 'Undo' and 'Redo' functions have been added, with unlimited levels. It is now possible to extricate yourself from most mistakes without too much trouble.

There is no electrical rules check to look for possible mistakes like unconnected pins and shorts, and there is no autosave feature. If you want to export your net list to a pcb program, you can do so in Orcad, Tango, PCAD, Protel and Redac formats.

Although Tina Pro's symbol library is well-stocked, it is possible to add your own symbols as there is a dedicated symbol drawing section. This is a good concept. The symbol drawing program is started separately from the main program, via the Tina start menu.

Drawing symbols from scratch using this editor and then implementing them was easy. You can attach Spice models to these symbols.

Another self-contained section enables Spice macros to be added.

Simulation

Tina Pro is described as Spice 3F5 compatible and features a native mixed-mode simulator.

There are seven main virtual instruments for performing analyses; an oscilloscope, a signal analyser, a function generator, a digital signal generator, a logic analyser, a digital multimeter, and an XY plotter.

When expanded, these instruments all have the appearance of real instruments, similar to the ones in Electronics Workbench. In addition there are several other measuring tools, including a power meter and impedance meter.

The manual and help files do not describe these meters as well as those in Workbench or CircuitMaker do. However, in most cases it is not difficult to find out what they are, and what they are capable of, simply by trying them out.

The method of use for the oscilloscope, signal analyser and multimeter instruments is to select these as icons from the parts bins – or component bars, as they are called in Tina – and wire them into the circuit diagram. The other virtual instruments can be selected from the T&M menu and connected via a virtual probe.

Instead of expanding an instrument icon to see the controls, etc., as in other programs, the system in Tina is to pick the instrument you want to adjust from the T&M menu. You then get the complete virtual instrument on the screen in a set size.

Instruments cannot be resized or run full-screen, but they can be moved around Windows-style in order to fit in more instruments or to look at the circuit diagram. A typical instrument – an oscilloscope – is shown in **Fig. 1**.

Alternatively, you can set up the virtual instrument from a short-form menu by clicking right on it but I did not find this method very useful. Generally speaking the range and extent of the virtual instrumentation was good.

Several of the meters from the meter parts bin are noteworthy. The power meter will be of interest to those of you involved in AC power circuits as it can give power factor, apparent power, reactive power, and phase. This is done not through a virtual-instrument type interface, but via the ac analysis nodal voltage dialogue box. It is not intuitive. To see the detailed readings, you have to place the probe on the power meter.

The other instrument that caught my eye was the impedance meter. This system is more direct than that in *CircuitMaker*. It is easy to use and intuitive. An example giving a graph of input impedance versus frequency of an active filter is shown in **Fig. 2**. By using the nodal voltage probe, as with the power meter, you can get values for admittance and phase.

The oscilloscope is not restricted to two channels as it is in *Workbench* for example. It can function like a normal oscilloscope or in storage mode.

Besides the virtual instruments, you can run analyses by fixing probes/instruments in place and selecting the type of analysis you require from the menu system. DC and AC analyses, and transient, and noise analyses are handled this way.

Where appropriate, Nyquist graphs can be displayed – an unusual and interesting feature at this level. All these graphs can be run full-screen for easy measurement. A typical AC analysis run from a menu is shown in **Fig. 3**.

The above-mentioned analyses can be modified from the 'mode' menu. This is a blanket system of applying temperature-stepping, parameter-stepping, worst case, optimum and Monte Carlo graphing methods to the above analyses. This is a logical way to organise these analyses.

It is possible to obtain a Fourier series or spectrum of thd. An easy and direct method is used.

Symbolic analysis can be performed to obtain an expression for the response of DC, AC and transient analogue simulations. For a low-cost simulator this is another unusual feature. It provides an alternative view of the behaviour of analogue circuits, particularly for some second-order effects.

Other arguments for it include better insight and understanding of the circuit under test. In addition, teachers may regard it as useful for instructing students. Figure 2 shows a typical result.

Digital analysis can be run step-by-step as well as normal mode. There is no coloured-wire system for clarifying more complex circuits, as in *Electronic Workbench*, but there is a pin-colouring system which gives some help on complex circuits.

In digital simulation, there is good control over glitch threshold value. Like many other simulators, Tina has a fixed threshold system for showing glitches, in this case the default value being 50% of the delay of the digital devices. However, this can be overridden with a value set by the operator, which makes it a much more useful system.

Lowering the percentage reveals more glitches, i.e. those with shorter duration, and *vice versa*. Again, this is implemented in a way that is simple and easy to use.

The simulator section has a strong educational bias. Faults can be set, an equation editor is provided to insert formulae into the schematic, and there is even an 'Exam' mode.

Another interesting feature of this program, which is noteworthy even if not really connected with simulation, is the availability of plug-in boards to provide real-time measurements from actual circuits. Results can be displayed alongside the predicted results to show up any discrepancy.

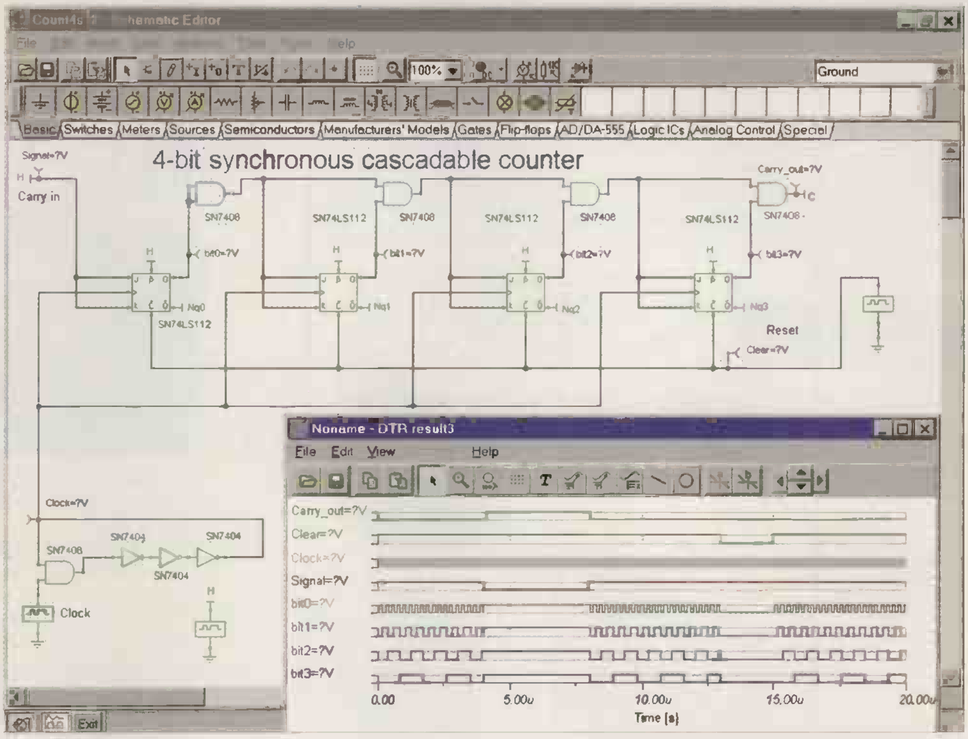


Fig. 5. The same chart as Fig. 4, but with a slightly enlarged timing chart, and with the glitch control set to 10%, showing the relevant glitches.

In summary

The first thing that existing Tina users will notice is how much improved the schematic drawing section is, compared to previous versions. It can now be said to be pleasant to use.

In the simulation section, the range and scope of the basic analyses offered in Tina Pro are excellent. All of the basic requirements of a simulation program as listed in the introduction are met. In addition, there are specialist features, like the power meter, Nyquist diagrams, and symbolic analysis, not found in other products at this price level.

The small written manual, brief Help files, and the style of the program give Tina Pro a medium-steep learning curve. I think a user manual comparable to that in CircuitMaker or Electronic Workbench would make the learning curve gentler and increase its appeal to many potential users – especially first-time CAD users. But Tina Pro would certainly suit those with even a modicum of experience in simulation.

The package is aimed at both the educational market, as it has many features only of use in this particular field, and at the design-engineer. Just as with other programs with an educational bias like Workbench and CircuitMaker, there is much to attract the practical designer. To Tina's credit, about 1Mbyte of the educational features can be omitted during the installation process if you wish.

For engineer and educationalist alike, Tina is good value for money. It's £100 more than Workbench or CircuitMaker, but the extra features make it well worthwhile. Tina continues to show rapid development, with an original approach, and promises to be one of the main contenders in this market sector. ■

Tina Pro V5.2
by DesignSoft
UK supplier; Quickroute Systems tel. 0161 4760202, fax 0161 4760505, price £299 for Tina Pro Industrial. Tina Pro Student version £49, Tina Pro Educational, £179. All prices exclusive. Site licences available; contact Quickroute.

Richard Brice looks at the evolution of music synthesis techniques from the Moog to wave tables.

Electronics and music

The analogue music synthesiser owes its genesis to Robert Moog. He invented the first commercial unit, which gave artistic inspiration to composers working in the early post second world war electronic music studios; composers of the stature of Stockhausen, Eimert and Berio. An early modular Moog synthesiser is illustrated in **Fig. 1**.

All analogue synthesisers contain certain cardinal circuit blocks each, originally, more at home in a laboratory than in a music studio. These are described later.

What Moog did was to take everything that the musicians had found useful at that time and build it all in a neat form so that all the various components interfaced properly.

Although many of the first customers were experimental musicians, it wasn't long before advertising agencies latched onto Moog equipment. The synthesiser turned out to be the perfect way to bridge the gap between sound effects and music.

Voltage-controlled oscillator

Fundamental to the whole concept of analogue sound synthesis is the voltage-controlled oscillator. This may be controlled by a switched potentiometer, perhaps arranged like a conventional musical keyboard. Alternatively, it may be controlled by a constantly variable voltage, thereby providing a sound source with endless portamento like the Ondes Martenot and the Theremin.

Control voltage for the VCO may also be controlled by the output of another oscillator resulting in one waveform frequency-modulated by another. And perhaps this resultant waveform might be made to modulate a further source! By this means, the generation of very rich waveforms is possible.

Design of voltage-controlled oscillator for audio synthesis applications is not altogether straightforward . This is because the oscillator must be made to swing over the entire audible range – a frequency range of some eleven octaves.

Often, the oscillator is a sawtooth generator type like that illustrated in **Fig. 2**. Note that the rate at which the integration capacitor charges in the feedback loop of the op-amp is variable by means of the adjustable current source. The circuit must itself generate the ramp termination pulse.

The self-generation of the termination pulse occurs due to the action of the comparator circuit, which has a pre-set negative voltage on its positive input terminal.

Once the ramp circuit output voltage – which is shown supplied to the comparator's inverting input – has reached this threshold, the comparator changes state. This closes the electronic switch shown connected across the integration capacitor. The charge-integrating capacitor is thereby shorted and the ramp terminates, allowing the whole process to start once again.

It's worth pointing out that there is nothing to stop an external pulse being sent to this oscillator in the manner shown in Fig. 2. This is often done in commercial synthesisers, a technique known as 'synching'. By setting the natural oscillation of one oscillator to a different frequency from that of its externally supplied synching pulse, some very complex waveforms are obtainable.

One major complication with voltage control for synthesisers is due to the nature of the relationship between control voltage and frequency.

From a technical point of view, the easiest control law to generate is linear, or V/F=k, where k is a constant. But from a musical standpoint, a law that relates a constant change in pitch (frequency) to a constant change in control voltage is far better. This is a logarithmic law and considerable complication exists within most analogue synthesisers to alter the control law of the VCO to that suitable for musical applications.

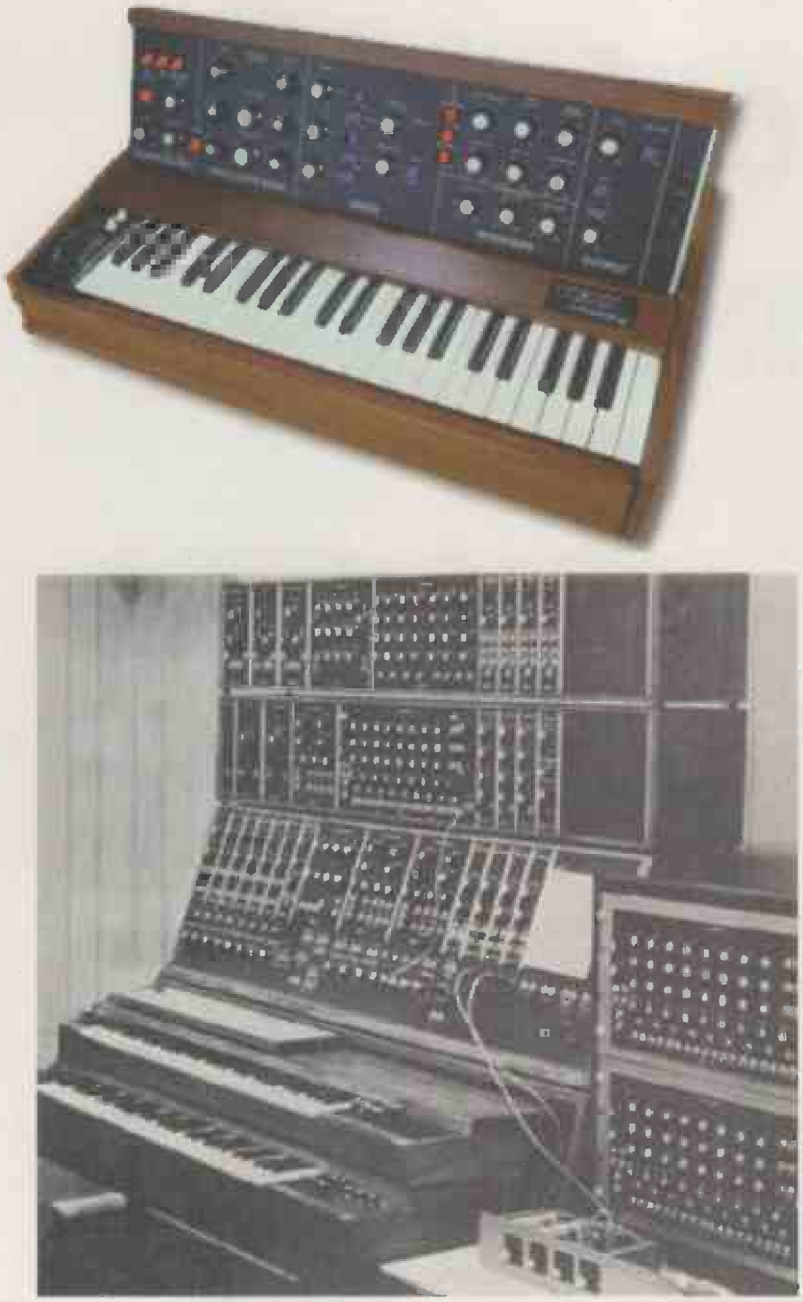


Fig. 1. Moog took al the electronic building blocks that musicians were using at the time and incorporated them into one instrument. Shown are an early Moog and the Minimoog.

Voltage controlled filters

A voltage-controlled filter, or VCF, is a frequency selective circuit that may be made to alter its cut-off frequency under the control of an externally applied voltage. The most usual type in synthesiser applications is the voltage-controlled low-pass filter, which is the most useful in musical applications.

A simplified schematic of a VCF is given in **Fig. 3**. This unusual circuit operates like this: The cut-off frequency is programmable by means of the current sink 'tail' which may be made to vary its sink current as in the manner of a normal current mirror. This current divides between the two cascode pairs and into the collector loads of Tr_3 and Tr_4; themselves another cascode pair.

At very low sink currents, the value of the collector loads Tr_1 and Tr_2 will be relatively high. This is because the output impedance from an emitter follower – which is what these loads are – is inversely proportional to emitter current.

Similarly, the transconductance of the differential pair will be low too. The gain of the stage will therefore be the product of the low-ish transconductance of the pair, multiplied by the relatively high impedance of Tr_1 and Tr_2 collector loads.

At high tail current, these conditions alter so that the transconductance of the differential cascode pair will be high, but the impedance of the collector loads – from which the signal is taken differentially – will be low. The overall low-frequency gain of the circuit will thereby remain constant; irrespective of changes in tail current.

What will alter however will be the available slew-rate of the amplifier which will be severely limited by the ability to charge and discharge C_1 and C_2 at low standing currents. At high standing currents, this situation will improve, thereby increasing the bandwidth of the circuit.

Sometimes practical circuits repeat the cascode structure of this circuit many times to increase the number of poles in the filter, often earning the circuit the name 'ladder filter'.

An important further function of the circuit is its ability to feed a proportion of the signal back to the other side of the differential pair. Note that this is not negative feedback but positive feedback. This has the effect of increasing the Q of the circuit – especially near the turnover frequency. It is therefore possible to produce a range of responses like those shown in **Fig. 3**. These offer a gamut of musically-expressive possibilities by permitting the possibility of imprinting high-Q formats on the fundamental wave.

Sometimes this Q control allows the possibility to produce instability at extremes of the control's range, thus turning the VCF into another, somewhat unpredictable, VCO.

Envelope generation

Real musical sounds have a dynamic envelope. Turning a primitive synthesised musical waveform into a musical sound involves imprinting attack, sustain and decay envelopes onto the fundamental sound source. This manipulation requires a controlled multiplication function. The attack is the speed with which a signal is multiplied from zero – i.e. silence – to a constant sustain level.

The rate at which the sustain level decreases back to zero once the keyboard key is released is the decay, or release period. The multiplication function is performed by a voltage-controlled amplifier or VCA.

Voltage-controlled amplification

Analogue multiplication techniques involve the use of current 'steering' via two alternative circuits to achieve such a multiplication. The circuit in **Fig. 4** demonstrates the general principle.

Essentially the audio signal at the base of the lower transistor is turned into a current in the collector circuit of the same transistor by the transistor's transconductance mechanism. Notice that a resistor is included in the emitter circuit to linearise this current. This collector current divides into two circuits, through Tr_1 and Tr_2, the ratio of the current being dependent on the voltage on the base of Tr_1. If this voltage is higher than the signal on Tr_2 base (V_k), current will flow predominantly through Tr_1 and appear as a voltage signal on R_r. If it is lower than the signal on Tr_2 base, current will flow predominantly in Tr_2.

By altering the value of the voltage on the base of Tr_1, a variable proportion of the original signal voltage (suitably inverted) can be recovered across R_r.

Attack-sustain-release generator

The controlling signal is derived from an envelope generation circuit sometimes known as an attack-sustain-release generator, or ASR, and an example is illustrated in Fig. 5.

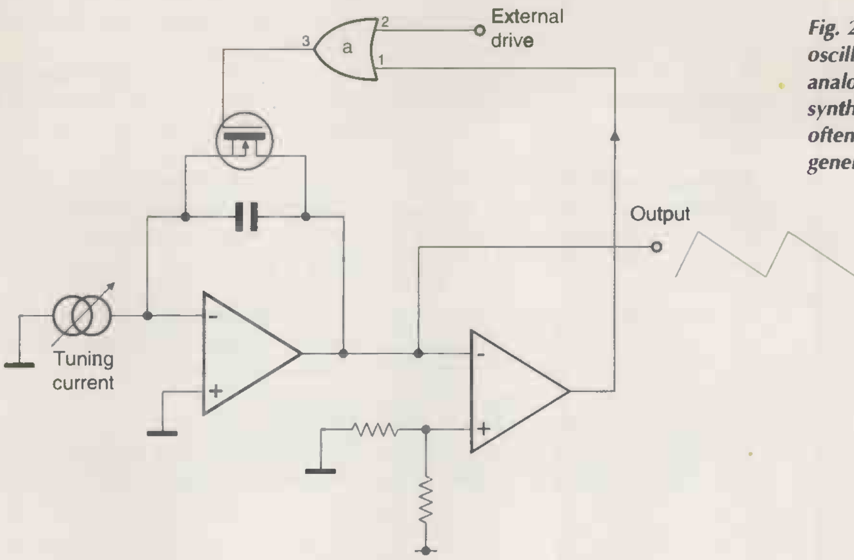


Fig. 2. The oscillator used in analogue synthesisers is often a sawtooth generator.

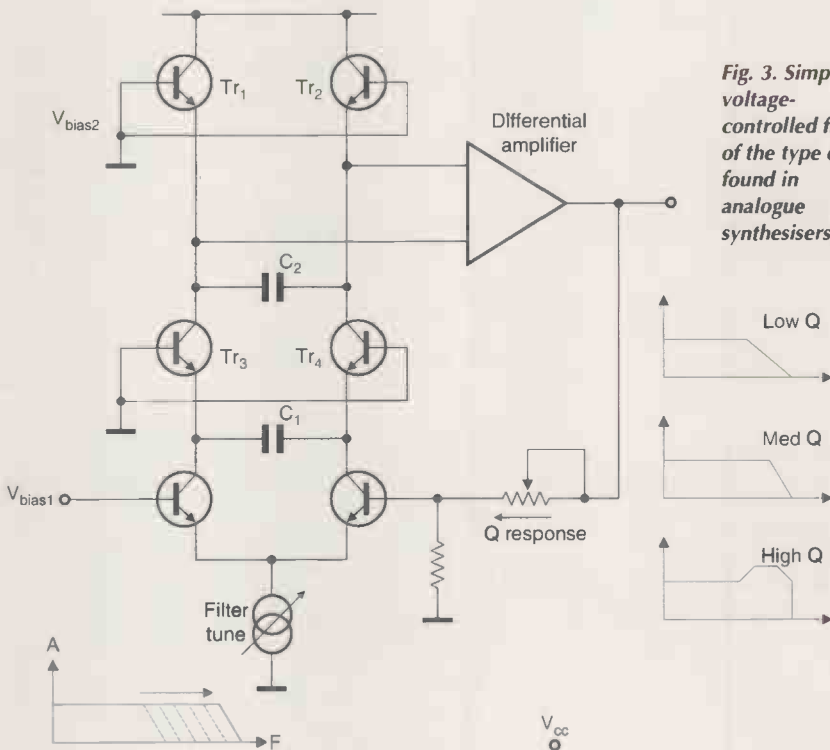


Fig. 3. Simplified voltage-controlled filter of the type often found in analogue synthesisers.

When the key closes the control voltage fed to the VCA rises at a rate predetermined by the setting of VR_1 and its interaction with C_1. Ultimately, the control voltage rises to the value set on VR_2 which determines the sustain level. Finally, once the key is released, the control voltage will fall as determined by the setting of VR_3 and C_1.

Low-frequency oscillator

The low-frequency oscillator is often a ramp generator, or sometimes Wien bridge type. External voltage control is seldom provided; instead the function of this oscillator is to control either VCA or VCO in order to pro-

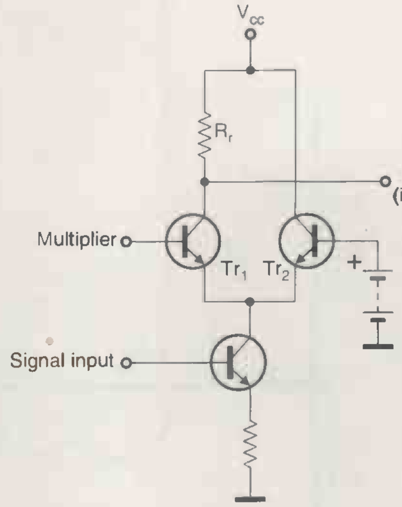


Fig. 4. Voltage-controlled amplifier involves turning the input voltage into current. The ratio of current in the two upper transistors is determined by the voltage at the base of Tr_1

vide tremolo or vibrato respectively.

Alternatively the LFO is often used to control a VCF, in order to obtain a protean musical timbre – one of the musical hallmarks of analogue synthesis.

Analogue noise generators

Analogue noise generators are relatively simple; often as no more elaborate than a resistor followed by a high-gain amplifier.

Another source of noise is a reverse-biased diode, followed by a high gain amplifier. This is a good generator of noise because the noise in a diode is relatively high. This is due to the avalanche effect as high-velocity electrons, entering the n-region from the p-region, liberate others in the valence bands of the n-region – a process that is inherently noisy.

Furthermore it side-steps a problem with a resistor circuit. In order to get a high enough noise voltage, a very high value of resistor must be used. This invites the possibility of other signals being electrostatically or electromagnetically coupled into the circuit; hum being especially problematic in this respect.

The diode, on the other hand, generates a comparatively high noise voltage across a low impedance.

Patching

In order to produce a practical, usable musical sound from an analogue synthesiser, each of the circuit blocks mentioned above must interconnect.

A simple patch – the name used for a particular interconnection scheme – is illustrated in **Fig. 6**. Notice that the keyboard controls the VCO to generate a pitch; the VCO is followed by the VCF to impart a character onto the basic sound source, and this is driven by the output of the LFO to create a changing formant; and the output of these modules is passed to the VCA block where the trigger-signal from the keyboard controls the ASR generator.

Figure 6 illustrates but one possible patch. Remember, the power of the analogue synthesiser lies in its ability to cause the various sound and noise sources housed within it to interact.

Commercial synthesisers differ greatly in the flexibility they present to the user; in terms of being able to route the various signals and thereby have control over the pattern of possible interactions.

Some synthesisers offer very limited re-patching, others permit virtually unlimited flexibility, so that practically any signal may be used as a parameter to control another process. Electrically this switching function may be provided by hardware switches, by electronic switches or even by a traditional telephone-style jack-field; as illustrated in Fig. 1.

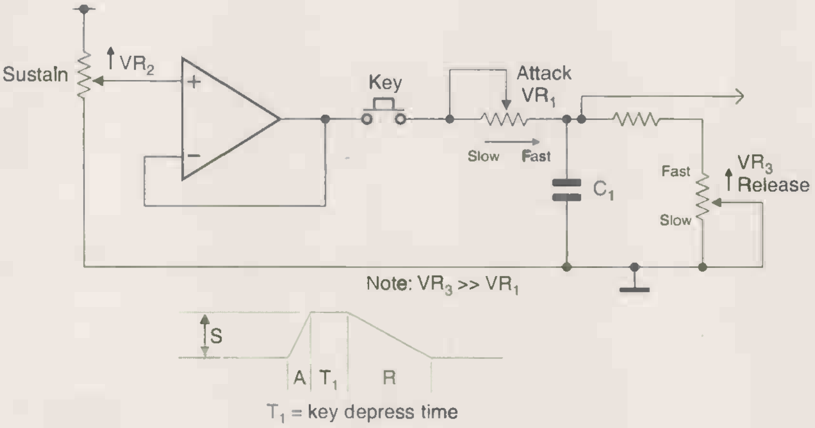


Fig. 5. To produce realistic music synthesis, an attack-sustain-release generator is needed to shape the note.

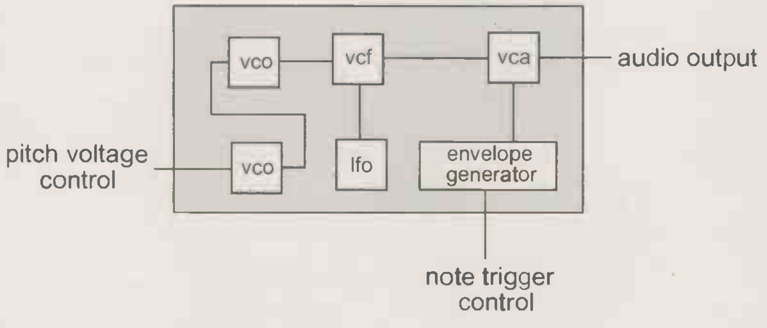


Fig. 6. How the circuit described in previous illustrations interconnect – known as a 'patch'.

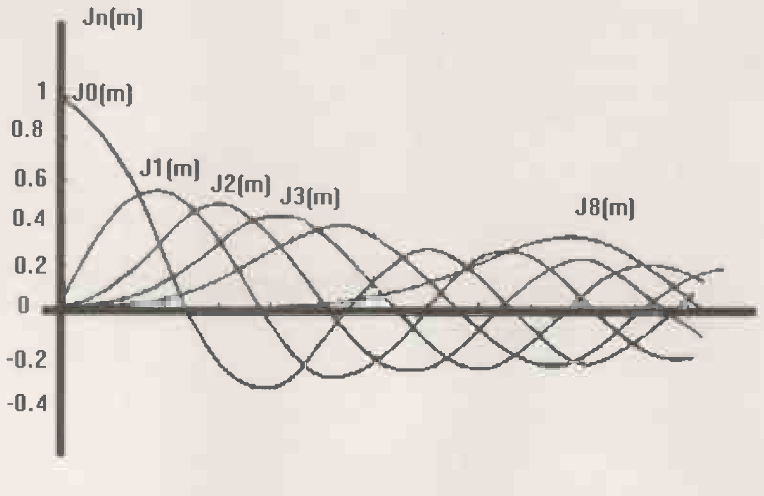


Fig. 7. A collection of first-order Bessel functions.

Digital synthesis techniques

One of the lessons learnt from analogue synthesis – and especially from controlling one oscillator from another – was that extremely complex timbres may be generated by relatively simple means.

In 1967 Dr John Chowning – a musician who had studied with Nadia Boulanger in Paris and subsequently set up a music composition programme at Stanford University – realised the possibilities of using frequency modulation to imitate complex musical sounds.

The complex nature of fm sidebands seemed to suggest that here might be a technique where complex musical tone-structures could be built up using one or two oscillators. Chowning was right, but he had to wait for the advent of digital techniques to guarantee the necessary stability, predictability and repeatability required for this synthesis technique.

Frequency modulation in detail

The sideband frequencies produced around a frequency-modulated carrier are related not only to the deviation as a proportion of the modulating wave frequency – the so-called modulation index – but to all the harmonics of the modulating frequency as well.

The structure of the resulting sidebands issuing from all these variables are determinable using mathematical relationships known as Bessel functions.

A collection of first-order Bessel functions is illustrated graphically in **Fig. 7**. These illustrate the harmonic content of the fm process. The abscissa value represents the modulation index – which is equal to the frequency deviation divided by the modulation frequency. The ordinate represents the amplitude value of the carrier J0 and the first eight harmonics, J1 to J8 respectively.

Intuitively, you can see that when the modulation index is zero – i.e. no modulation – all the energy in the resulting output is concentrated in the carrier: That is, J0 is unity and all the other functions J1 through 7 are zero.

As the modulation index increases slightly, J0 declines and J1 climbs. Note that J2, 3, 4, etc., climb more slowly. This illustrates why low modulation index fm has a spectrum similar to that of amplitude modulation, with only first-order sidebands. It also illustrates that a signal modulated with a very high modulation index will have a very rich spectrum indeed.

At this stage, you may find yourself asking, "OK, I can see frequency modulation produces complex harmonically related structures around a carrier; but doesn't that mean that the carrier would have to be different for each note of the keyboard? And what happens to the lower sidebands since these don't normally exist in the case of a musical sound?"

A carrier at zero hertz?

The answer to the mystery is that the carrier used in fm synthesis is zero hertz! It is the modulating signal that determines the fundamental frequency, and the depth of the modulation, or modulation index, which may be manipulated to produce the harmonic structure above the fundamental.

Look at the figure of Bessel functions and imagine that a modulating frequency is employed that relates to the note middle C; 261Hz. Suppose a deviation is chosen of 261Hz, that is with a modulation index of 1.

From the curves in Fig. 7, it's clear that at m=1, J1 equals about 0.45 and that J2 equals about 0.1, all the other harmonics still remaining very small at this low index. The resulting sound – suitably synthesised, amplified and transduced – would be a note at middle C with a second harmonic content of about 22%. The zero-hertz carrier would, of course, effect no audible contribution.

This might make a suitable starting point for a flute sound. Now imagine a

Fig. 8. Yamaha's DX7 – the first synthesiser to use frequency-modulation techniques.

much greater modulation index being used: m=3, for example. Reading off from the curves, it shows that in this case; J1=0.34, J2=0.49, J3=0.31 and J4=0.13. This would obviously create a much richer musical timbre.

If the index of modulating signal is changed over time, it is possible to create musical sounds with extremely rich musical transients, full of spectral energy which then segue into the relatively simple on-going motion of the resulting note. In other words, it is possible to create synthetic sounds just like real musical sounds, where a 'splash' of harmonics is created as the hammer hits the piano string, or the nail plucks the string of a guitar, or as the first breathy blast of air excites the air inside a flute. All of these decay quite rapidly into a relatively simple on-going motion.

Each of these effects may be synthesised by generating a modulating signal that initiates the carrier modulating with a large deviation, creating a rich transient part to the sound. This then decays to a level where it causes only relatively small deviation, generating a relatively pure on-going sound.

A complication arises as a result of the choice of the zero frequency carrier. Just because the carrier is zero hertz, it doesn't stop there being sidebands in the negative frequency region. These 'fold back' into the positive frequency region and destructively interfere or constructively reinforce the sidebands present there already. These too have to be taken account of in generating fm synthesis algorithms.

But there are other more interesting uses for the lower sidebands and these embrace the use of a very low frequency carrier instead of one of zero frequency. When a low frequency carrier is used, the negative frequency sidebands fold back into the positive region to be interleaved with the positive frequency sidebands. In this manner, even more complicated timbral structures may be built up.

The DX7

FM synthesis techniques were first used commercially in the Yamaha *DX7* keyboard, **Fig. 8**. At the time, it caused a sensation in synthetic music.

So successful was the method and so excellent Yamaha's implementation, that the 'sound' of the fm synthesis *DX7* dominated the popular music of the eighties. Artists who used it include Talking Heads, Brian Eno, Cabaret-Voltaire, D:Ream, Front 242, Depeche Mode, U2, A-Ha, The Cure and Enya.

Frequency modulation is remarkable in that it represents the high-point of pure, electronic sound generation. It still remains the sound technique employed in cheaper PC sound cards.

Sampling

Digital sampling systems rely on storing high-quality, digital recordings of real sounds and replaying these on demand.

The tough problem in sampling is the amount of memory it requires. Sampling is well suited to repetitive sounds like drums and other percussion instruments. This is because the sample is mostly made up of a transient followed by a relatively short on-going sustain period. As such, it may be used over and over again so that an entire drum track could be built from as few as half-a-dozen short samples.

Problems arise when long, sustained notes are required; like the sounds generated by the orchestral strings. The memory required to store long sustained notes would be impossibly large.

Pure sampled-synthesis systems rely on 'looping' to overcome the limitation of a non-infinite memory availability.

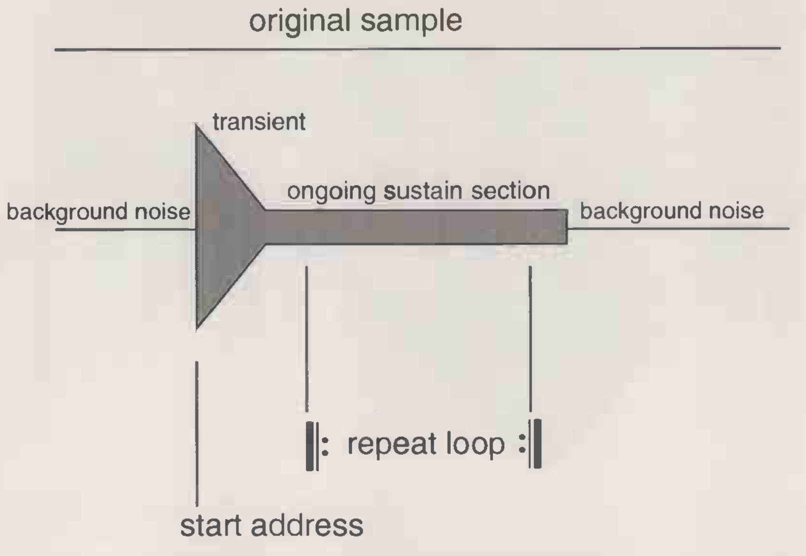


Fig. 9. To reduce the amount of memory needed, modern samplers repeat a section of the sustain period.

But a loop is hard to achieve without either sacrificing the starting transient of the note or having it repeat over and over as the loop repeats, resulting in a 'hiccup'. Modern samplers provide start and loop-point memory address programming for just this reason, as illustrated in **Fig. 9**.

An important part of sampling technique involves the use of one acoustic sample over a group of notes. Replay of the sample at the appropriate pitch is achieved by the applicable modification of the read-clock frequency in exactly the same way as pitch-shifting (described in my last article).

In theory, one sample may be used at every pitch. However, due to distinctive formants imprinted on the sound by the original voice or instrument, this can result in an unnatural sound if the transposition is taken too far. This effect is known as Munchkinisation, named after the under-speed recorded singing Munchkins in The Wizard of Oz.

The effect is ameliorated by recording several samples at different pitches and assigning these to various ranges of transposition. Furthermore, samples are usually recorded at various different dynamic levels from very quiet (pianissimo or pp) to very loud (fortissimo or ff).

The sampler uses these different samples and a mixture of samples at different dynamics points, to achieve touch-sensitive dynamics from the controlling keyboard. Good sampling technique therefore involves judicious choice of looping-point, transposition assignments and dynamics assignments. This is no mean task and successful sampling programmers are very skilled people.

Wave-table synthesis and the like

The technique known as wave-table synthesis involves sound samples in combination with a number of special techniques. These include carefully edited looping points, pitch shifting, interpolation and digital filtering to reduce this prohibitive memory requirement.

The system is known as wave-table because the synthesiser employs a group – i.e. a table – of different sound segments which it 'looks-up' and utilises as required.

Other proprietary synthesis algorithms have included LS Sound Synthesis from Roland and Dynamic Vector Synthesis from Yamaha. Both these techniques use what might be termed 'empirical' sound synthesis techniques. They involve a mixture of sampling and tone generation – by additive of FM synthesis – to arrive at their final result.

Sound synthesis like this tends to be a non-purist subject based on subjective 'feel' rather than mathematical precision.

Modern trends in synthesiser design

The method of synthesis employed in the 'classic' three-VCO and filter synthesiser like Moog's *Minimoog* is sometimes referred to as subtractive synthesis. This term is a little misleading. It relates to the situation whereby the fundamental tones produced by the VCOs are of a complex harmonic structure in the first place. These are subsequently filtered and modified in the filter and envelope circuits, thereby simplifying the harmonic structure by 'subtracting' harmonics.

In exactly the same way, the voice may be considered a subtractive synthesiser. This is because the vocal chords produce a crude but harmonically complex 'buzzing' fundamental tone which is capable of being modulated in pitch alone and on which is imparted the filtering formants of the mouth and nasal cavities.

Nature, always a parsimonious architect, adopted such a system because it is efficient. However, while subtractive synthesis is a very potent arrangement and fm techniques and sampling all offer their particular advantages, there is another approach that offers the ultimate in synthesis technology. It is known as additive synthesis.

Additive synthesis

I mentioned additive synthesis in an earlier article when looking at the classic tone-wheel Hammond organ.

Hammond's implementation was Neanderthal by today's synthesis standards. But despite the crude nature of their synthesis algorithm – and that simply means the limited number of harmonic partials they had available – additive synthesis represents the 'ultimate' synthesis algorithm because it's Fourier analysis in reverse!

Of course, Hammond's engineers didn't adopt a limited number of partials out of choice. They were thwarted by the technology of their period. Very-large-scale integration, i.e. VLSI, integrated circuits offer the possibility of the literally huge number of oscillators necessary to produce convincing synthetic sounds by this means.

Physical modelling

Instead of concentrating on the sound events themselves, some workers in synthetic sound have chosen a different route; to model mathematically the results of a physical system.

Using this technique, a guitar sound is modelled as a stretched string, with a certain compliance, mass and tension. These are coupled to a resonant system excited into sound by means of a excitation function. The excitation function itself is modelled to represent the action of plucking a string.

That this technique is computationally intensive is something of an understatement. However, it has already proved to be a fruitful synthesis approach. It also offers the possibility of modelling new sounds of impossible instruments, which is especially interesting for composers searching for new sounds of ostensibly 'physical' or 'acoustical' origin. ■

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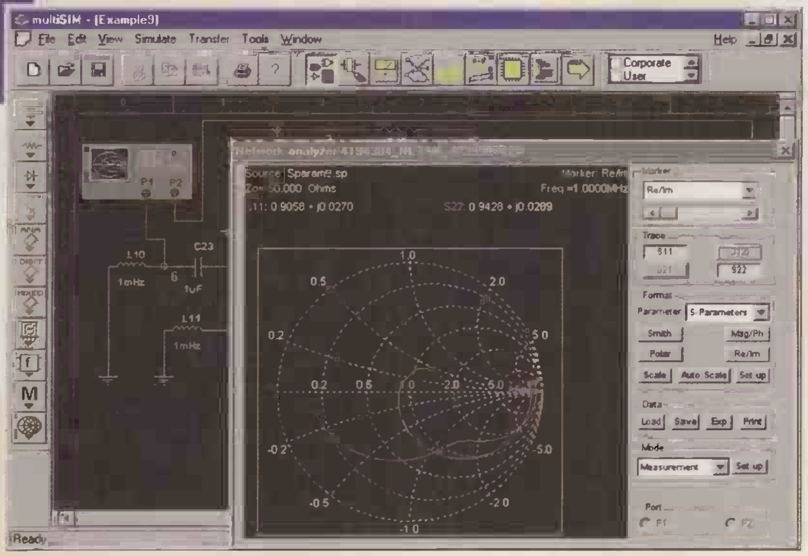

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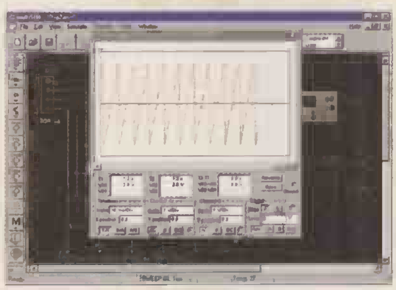

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NEW PRODUCTS

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20-bit d-to-a converter

Burr-Brown's *DAC1220* from Silicon Concepts is a 20-bit digital-to-analogue converter using delta-sigma technology. The 2.5mW device comes in a 16-lead SSOP. Applications include high-resolution test and measurement systems, and portable, battery-powered and isolated systems. It can be operated in 16- or 20-bit mode

from –40 to +85°C. In 16-bit mode, settling time is 2ms to 0.012 per cent and linearity error over range less than ±1LSB. Output range is 0V to twice the external reference voltage and it has on-chip calibration circuitry. The device operates from a nominal 5V supply and consumes less than 3.5mW in 16-bit mode. In sleep mode, current consumption drops to less than 0.5mW. Communications are via a serial interface for writing and reading of the five onboard registers.

Silicon Concepts
Tel: 01428 751617
Enquiry No 501

Design Software

Actel has announced a direct time layout timing-driven place-and-route software module to control placement of critical nets for the firm's *SX* FPGAs. The software has been included in the firm's just-released, free Designer R1 1999 software update.

Actel
Tel: 01256 305600
Enquiry No 503

Evaluation kit

The *Topas 900* flash starter kit from Toshiba contains all the hardware, software and documentation needed to design, test and implement applications based on Toshiba's *TMP95FY64* 16-bit microcontroller with onboard flash memory. Evaluation and test functionality includes in-circuit debug and field flash programming. The kit provides a plug-and-play development environment that lets designers compile prebuild projects, download, debug and run program examples, change or update the ROM monitor in flash, and program the MCU's on-chip flash memory.

Toshiba
Tel: 00 49 21 5296210
Enquiry No 504

Switching regulators

Telcom has announced a series of monolithic, off-line switching regulators, the *TC33370* to *TC33374*. The devices have multiple on-chip functions for off-line power converters. Made using the *SmartMOS* process, they operate from a rectified 85 to 276V AC line source at 100kHz. A biCMOS controller and high-voltage and low-voltage transistors are on the same chip used to drive the primary side of a transformer in flyback mode applications. They come in five-lead TO-220 plastic packages. An integrated programmable state controller allows implementation of four on-off control methods of the converter – primary side manual toggle on-off, secondary side microcontroller toggle on-off, primary side toggle request with secondary side, and programmable on or off state on application of AC power. The on-off feature provides a way to obtain low standby power in printers, fax machines, VCRs and DVDs.

Telcom Semiconductor
Tel: 001 650 968 9241
Enquiry No 505

Tuner IC

Maxim has introduced the *Max2108* zero-IF digital satellite tuner IC, which directly downconverts L-band signals to baseband I/Q channels. There is no need for an IF local oscillator, IF mixer and saw filter. The 8dBm IIP3 at minimum gain lets the RF input be directly connected through a matching network to the F-connector of a 75Ω cable without the need for a pin-diode attenuator and amplifier.

Maxim
Tel: 0118 930 3388
Enquiry No 507

2.5V MAX PLDs

Thame Components is offering Altera's latest *MAX 7000B* device family of programmable logic devices (PLDs). The 2.5V EEPROM-based devices offer propagation delays of 3.5ns and counter frequencies of over 200MHz. The family are product-term-based devices that support Gunning transceiver logic plus (GTL+) and stub series terminated logic (SSTL-2 and SSTL-3). The PCI-compliant MAX 7000B devices range in density from 32 to 512 macrocells and offer features such as 2.5V in-system programmability (ISP), support for the vendor-independent Jam Standard Test and Programming Language (STAPL), and built-in Joint Test Action Group (JTAG) boundary-scan test support. MultiVolt I/O operation allows the devices to interface between 1.8V, 2.5V, and 3.3V devices.

Thame Components
Tel: 01844 214215
Enquiry No 506

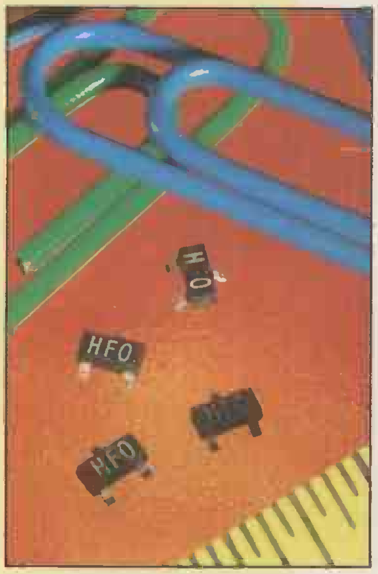
Receptacle

Hirose has added a receptacle to its *MU* fibre optic connector range. Based on NTT design, the *SR* is for high density equipment front panels

DSL over single twisted-pair cable

Micro Call has introduced an HDSL2 chipset offering symmetric digital subscriber line technology over a twisted pair cable. For business applications, it is compatible with ADSL, HDSL and ISDN services. The Level One *SK70740*, *41* and *42* provide an analogue front end, transceiver and FEC framer. The chipset supports line rates up to 2.064Mbit/s and sub rates down to 144kbit/s. The *SK70741* and 42 have 8-bit parallel interfaces for connecting to standard Intel or Motorola processors. An internal activation controller in the *SK70741* reduces software complexity and processor overhead.

Micro Call
Tel: 01296 330061
Enquiry No 502



Varactors

The *KV* surface-mount varactors from Link Microtek come in plastic SOT-23 packages. Made by Narda, the silicon varactors – or variable capacitance diodes – use super hyperabrupt junction technology to deliver tuning ratios up to 13:1. These microwave discrete semiconductor devices are for fixed or mobile wireless applications up to about 1.5GHz.

Thame Components
Tel: 01844 214215
Enquiry No 508

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and general high density patching. Available for simplex, duplex, eight way and 16 way adapters, the *SR* receptacle lets a device or internal pigtail be terminated with a ferrule only assembly. The IEC61754-6 *MU* system has push-pull latching and uses a 1.25mm ferrule.
Hirose
Tel: 01908 260616
Enquiry No 509

Bus switches

Fairchild has introduced three undershoot hardened bus switches. The *FSTU* 10-bit switches have integrated circuits that sense undershoot levels of more than –2V on an i/o data port and provide a bias voltage override to maintain the switch in the isolation state. They are for servers, data routers, network and telecoms switches, and raid systems that require peripheral and network card hot-swap capability. The switches isolate peripheral and network interface cards from their PCI or CompactPCI bus during live insertion and withdrawal. The family comprises the *FSTU3384*, the *FSTU6800* with precharged outputs and the *FSTU6800A* with high-speed enable.
Fairchild Semiconductor
Tel: 01793 856856
Enquiry No 511

RFI filters

Single phase RFI suppression filters from Timonta are for applications with non-sinusoidal waveforms, such as switched mode power supplies. The filters have high inductance common mode chokes in the first stage and independent differential mode chokes in the second stage, and are combined with Y capacitors in both stages. The FSS filters are available in aluminum housings for chassis mounting and are for equipment where electronic switching processes with high repetition rates occur, including power supplies, ultrasonic generators and static DC converters. Current ratings are from 1 to 3A with leakage currents of 0.5mA, and 4 to 16A with leakage currents of 3mA.
Timonta
Tel: 01929 555800
Enquiry No 513

I/O connector

AMP has extended its *Duac* wire-to-board connection system to include a version for power applications. Suitable for i/o use, the connector has a 4.2 by 5.5mm centre line. With dual action receptacle contacts, the *Duac/PL* is for mate-first, break-last applications and includes secondary locking for contact retention and positioning. A positive latch helps prevent disconnection, and it has an anti-stubbing design and polarised housing. It comes in four, six and 12-position versions, with either a right angle or vertical pin header. The standard range comes with a 4.2 by 4.2mm centre line and has a vertical header with mounting pegs and drain holes. Receptacle contacts are for 26-22 AWG and 22-18 AWG wire.
AMP
Tel: 0181 954 2356
Enquiry No 512

Passive networks

BI has introduced a surface-mount thick-film integrated passive network that can combine chip capacitors, inductors, ferrite beads, thermistors and diodes, as well as resistors and screened capacitors, in various configurations. The *628 RC* is for use in filtering applications and is based on the firm's *628* 16-lead gull-wing SOMC. It provides circuit functions from capacitor arrays and integrated filter circuits to diode networks. Screened components available include resistors from 10Ω to 1MΩ, capacitors with X7R dielectric from 10 to 100pF, capacitors with Z5U dielectric from 10 to 220pF and either PTC or NTC thermistors with maximum nominal resistance values of 1 and 100kΩ respectively. Up to six 0603 sized chips can be included from a list comprising inductors with inductances from 0.047 to 33μH and ferrite beads from 30 to 1800Ω at 100MHz with current rating 50 to 1000mA.
BI Technologies
Tel: 0116 278 1133
Enquiry No 514

Display assembly

To increase the range of chips that can be used in a cob or tab format, Densitron can assemble wire bonding devices with pitches down to 100μm for displays using single or twin chip drivers. The *LM4900*, for example, offers 32 x 96 pixels with an onboard dc-to-dc converter and LED backlighting in a 6mm thick package.
Densitron
Tel: 01959 700100
Enquiry No 515

Pushbutton switches

The *A16* pushbutton switches and indicators from Omron use a modular design. The 16mm diameter pushbuttons have a behind-panel length of 28.5mm. They can be assembled from separate flange, case, indicator lamp and switch units. They have a snap-in design. A tool is provided that allows lamp replacement from the front of the panel. The contact block can also be removed with the aid of a tool. The terminal arrangement allows push-on connectors or a direct soldered connection. They are sealed to IP65 and switch guards and dust covers are available.
Omron Electronics
Tel: 0181 450 4646
Enquiry No 510

Panel lamps

Instrument panel indicator lamps wearing captions describing their associated signal functions are available from Oxley Developments. For front panels of industrial and commercial equipment, the lamps can be supplied with various standard captions including up, down, left, right, stop and start, as well as customer specified short captions engraved on the front shroud. Each lamp has a rugged glass and metal construction and is sealed to IP68. Features include a choice of flying

lead or tag terminations, various colours including blue and white, and an integral resistor option that lets the lamps operate at up to 28V DC.
Oxley Developments
Tel: 01229 582621
Enquiry No 516

Schottky diodes

International Rectifier has available 12A D-Pak Schottky diodes for power

supplies from 25 to 50W. They are configured as dual 6A common cathode devices with a 12A current rating to reduce forward voltage drop. Maximum junction temperature is 150°C.
International Rectifier
Tel: 01883 733410
Enquiry No 517

Power controller

A solid-state remote power controller from ETA switches and protects resistive, inductive and lamp loads in DC circuits. For process control and

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industrial automation applications, the E1048 provides inrush current limiting, disconnection on overcurrent and short-circuit, and wire break monitoring for applications up to 24V DC in current ratings from 0.5 to 4A. It monitors the load circuit in process control applications involving switching of motors, solenoids and lamps, and provides power amplification for PLC outputs in industrial automation. The controller monitors circuits that are on or off. Status conditions are shown by two LEDs. The plug-in unit is 12.5mm wide, and uses an opto-decoupled transistor switch, physically isolating the control signal, load output and fault indicator.
ETA Circuit Breakers
Tel: 01296 420336
Enquiry No 518

Filters

Faraday has introduced high definition and wide screen pre and post antialiasing filters, including a range for single pass or monitor applications. They meet relevant SMPTE and ITU specifications. Complementary pre and post chrominance and luminance filters are matched for insertion delay to within an integer of the luminance clock period after taking the reconstruction delay into account. The filters are also available as zero loss options to improve impedance matching and performance. They can be shielded in metal cases, and are suitable for solvent and aqueous board cleaning systems.
Faraday Technology
Tel: 01782 661501
Enquiry No 519

High current PCB relay

Finder Components has launched a low-profile relay for PCB use. Dubbed the 41 series, the devices stand 15.7mm high. Three basic models are available covering a DPDT version with 8A switching capacity followed by two SPDT models with 12A and 16A ratings. All are capable of switching up to 250V AC. Both AC and DC coil types are available, the former from 24V to 230V, and the latter in versions spanning from 12V to 110V. Operating time for the relays is a quick 7ms for pick-up and 8ms for drop-out.
Finder Components
Tel: 01785 818100
Enquiry No 532

Electrolytics for all

Four ranges of surface mount and radial electrolytic capacitors manufactured by NIC are available from TTI. The *NRSA* and *NRSZ* ranges comprises radial leaded electrolytic capacitors, while the *NACED* and *NACZ* series are both surface mount electrolytics. *NRSA* capacitors are available in the range 0.47 to 10,000µF at ±20 per cent tolerance. Operating voltages are from 6.3 to 100V DC. They are general purpose devices with an operating temperature range of –40°C to +85°C. *NRSZ* components are low-impedance, high-frequency capacitors. They are suitable for applications in switching converters and provide long life operation at temperatures from –55°C to +105°C. Capacitance values are from 0.47 to 12,000µF at between 6.3 and 100V DC, and ±20 per cent tolerance.
TTI
Tel: 01494 565884
Enquiry No 533

IR transmitter and receiver

Rohm has launched a surface mount infra-red transmitter and receiver pair for consumer and professional remote-control applications and equipment such as domestic metering systems where electrical isolation is important. Based on 950nm GaAs technology and offering a maximum emitting strength of 11mW/sr at 20mA, the SIM-011ST LED has a maximum forward current of 40mA and a maximum reverse voltage of 5V. The corresponding *RPM-011PB* photo-transistor has a typical operating current of 1.0mA, falling to a maximum of 0.5µA when no light is detected.
Rohm Electronics
Tel: 01908 282666
Enquiry No 520

Resistors

Dubilier has introduced three metal strip resistors for surface mounting. They operate at temperatures up to 275°C. The 2.5W RLSP has resistances from 0.003 to 0.05Ω, the 2.5W wire wound RSPW covers

0.051 to 9.1Ω and the 1.5W metal film RSPM provides 10Ω to 10MΩ, all with tolerances of ±1 or ±5 per cent. The RLSP has a temperature coefficient of ±200ppm/°C, the RSPW –80 to +200ppm/°C and the RSPM ±50ppm/°C.
Dubilier
Tel: 01371 875758
Enquiry No 537

DTV development suite

VLSI Technology's Horizon II digital TV (DTV) set-top box development platform can be adapted to meet the

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requirements of digital television service in any part of the world, such as Canal+, BSkyB, ONdigital, TPS, ViaDigital, Kirch, OpenCable and SkyPerfecTV.The Horizon II platform is a complete offering that includes the ViSTA '99 chip-set, a development board, ViSTA '99 API, *JumpStartXE* development tools, documentation and sample applications. It can be configured for either cable, satellite, or terrestrial television signal reception, or it can be connected to a video stream station. It supports video capture from external video sources, such as a camcorder or a VCR. It also offers a multitude of connectivity options ranging from IEEE1394, IEEE1284, smart cards, IR capture and blaster, cable modem, telephone modem, DVB-CI, OpenCable POD, Bluetooth wireless home networking, and a range of PCI based peripherals such as Ethernet, USB, and IDE hard disk controllers.
VLSI Technology
Tel: 01908 667595
Enquiry No 521

Connectors and flat cable

Pancon has developed the *Lat-Con* IDC system with lateral flat cable insertion. The insulation-displacing contacts have a spacing of 1.27mm. Features include gas-tight connection and penetration of the flat cable with simultaneous automatic wire stripping, which leaves no insulation remains in the active contact area.
Pancon
Tel: 00 496172 1750
Enquiry No 523

DC-to-DC converter

Vicor has introduced predefined models in its 300V nominal input family of dc-to-dc converter modules for off-line applications in telecoms and mainframe systems. Input range

is 180 to 375V. There are three package sizes each offering outputs of 2, 3.3, 5, 12, 15, 24, 28 and 48V DC at output powers from 50 to 500W. Compatible accessories will include 300V input attenuator and filter modules.
Vicor
Tel: 01276 678222
Enquiry No 524

Radio modem

ST2E has released a 434MHz radio modem, the *RM4* from Rep Design, for licence-free data and telemetry applications. It is an FSK modulation modem suited to point-to-point or point-to-multipoint links at up to 19.2kbit/s asynchronous data rate with optional error correction. With 10mW output power as standard and a 0dB omnidirectional antenna, it can achieve a range of 1.5km in open space, while being ETS300-220 compliant. Receiver threshold is −100dB, and it has a single-board architecture for modem and RF

circuits and a standard RS232 interface. It operates from a DC supply between 8 and 14V, consuming 210mA in transmission and 120mA during reception. It is shipped with a 100 to 250V AC power supply and can be supplied with an outer enclosure or as an OEM board. Size is 105 x 80 x 30mm.
REP Design
Tel: 01462 670770
Enquiry No 525

VME bus board

Datel has introduced the DVME-614N multi-channel analogue-digital input board for VME bus computers. It is configured on a 6U VME outline and includes two 14-bit a-to-d channels

SDI video and AES, ASI signal splitters

The *Faraday* passive splitter provides an easy and low cost solution to the problem of providing two SDI or AES feeds from one source. For short runs of cable it can replace digital distribution amplifiers saving cost, space and running expenses. From a good SDI source it will support up to around 40m of Belden 8281 cable.
The device is fitted with BNC connectors and does not require a power supply. It may be simply 'hung' on the cable or where multiple units are required fitted onto a 1U high 19in rack, which can be supplied.
Faraday Technology
Tel: 01782 661501
Enquiry No 522

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with simultaneous sampling on each channel at 5MHz per channel. Applications include FFTs, DSPs and array-processor front ends. The board uses an A24:D16 VME interface. Features include onboard Fifo memory for up to 16384 samples, analogue input comparator channel and non-bus burst parallel port for seamless non-stop recording.
Datel Systems
Tel: 01256 880444
Enquiry No 526

Echo canceller

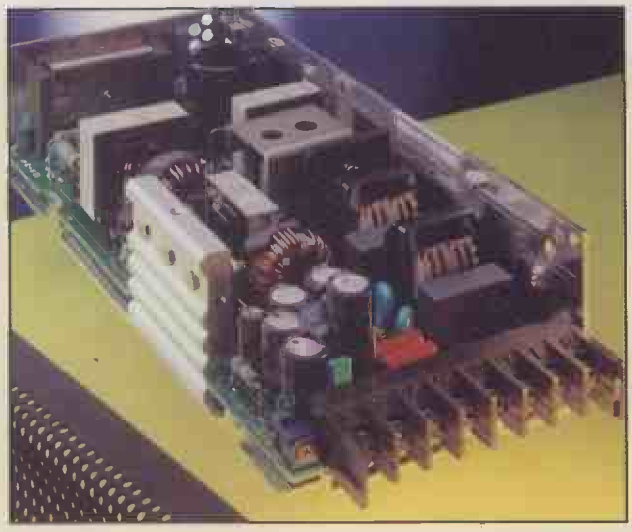
The *EC4420* from Kenton Research is a dual-channel echo canceller for fixed and mobile telephone installations. It provides up to 30dB attenuation for echo delays up to 55ms. Applications include long-haul four-wire circuits, acoustic echo cancelling, voice processing delay on multiplexers, and echo reduction in mobiles.
Kenton Research
Tel: 01322 552000
Enquiry No 527

Electronic load interface

Eltest has released the *EL-IFB-LPT1* interface board for serial-input electronic loads. It provides a way to configure up to 256 EL2, EL3 or EL4 serial-input 100W loads into burn-in rack and load bank configurations using a PC's parallel port. A 30-pin connector is used for interfacing with the parallel port and distributing 5V power to each unit. The 5.1 by 7.6cm board plugs directly into the top of an *EL2, 3* or *4* serial load and provides screw connections to the load and IDC flat cable connections to the LPT port. The interface board also becomes the mating socket, to 20A capability, for the devices. Devices can be operated in parallel for higher power. Two rotary hexadecimal switches decode one of 256 possible addresses for each load. The first rotary switch selects one of 16 banks or loads, and the second selects one of 16 devices within a load bank.
Eltest
Tel: 00 1 508 339 8210
Enquiry No 528

LCD module

A two-line by 16-character alphanumeric LCD module, with a 3.1mm character height and LED backlight is available from Anders. With a viewing area of 36 by 10mm and outer dimensions of 53 by 20 by 8mm, the *DEM16223SY* weighs 15g and is available with or without yellow-green LED backlight. Character size is 1.85 by 3.15mm. A transflective polariser improves clarity, and it has an integral flexi-cable link to the motherboard via an IPC connector. Operating temperature is 0 to 50°C and storage temperature –10 to +60°C.
Anders Electronics
Tel: 0171 388 7171
Enquiry No 530



Switched mode supply is 1.5in. high

A switched-mode power supply for computers and telecoms systems is available from Coutant Lambda. From 1in. to 1.5in. high with a footprint of 3in by 5in, the *SC* supply is available in 25 options. It comes in 26 to 80W versions delivering outputs of 3 to 48V. Single, dual and triple output options are available with line and load regulation of ±2 per cent on single output units and ±2 to ±5 per cent on multiple output ones. Input range is between 85 and 264V AC at 47 to 63Hz. Overvoltage and short circuit protection with automatic recovery are provided.
Coutant Lambda
Tel: 01271 856666
Enquiry No 529

RF testers

Schaffner has launched eight RF test packages for automotive component manufacturers. Each model in the *Profline 5100* series complies with ISO11452 and SAEJ1113. Test methods and frequency ranges covered are: direct injection from 250kHz to 500MHz; bulk current injection from 1 to 400MHz; three packages for radiated test methods in screened rooms and absorber-lined chambers, covering frequencies from 10kHz to 18GHz; strip line from 10kHz to 200MHz; tri-plate from 10kHz to 50MHz; and TEM cell from 10kHz to 200MHz.
Schaffner
Tel: 01734 770070
Enquiry No 531

Frame grabber

Cognex has introduced the *MVS-8100C* acquisition-specific PCI frame grabber for acquiring and displaying images in colour. It provides real-time image transfer to the host PC for analysis so operators can monitor inspection operations involving coloured parts. Images can be acquired using one RGB camera or two multiplexed RGB cameras. For monochrome applications, the board can support up to four multiplexed *RS170* cameras. It can also be used for simultaneous acquisition from two *RS170* cameras in, say, bottle inspection where one camera looks at a bottle's label for proper positioning while the second checks the cap for a proper seal.
Cognex
Tel: 01908 206000
Enquiry No 534 ■

SMALL SELECTION ONLY LISTED - EXPORT TRADE AND QUANTITY DISCOUNTS - RING US FOR YOUR REQUIREMENTS WHICH MAY BE IN STOCK

HP New Colour Spectrum Analysers LAST FEW ONLY
HP141T+ 8552B IF + 8553B RF -1KHZ -110Mc/s - £500.
HP141T+ 8552B IF + 8554B RF -100KHZ -1250M - £600.
HP141T+ 8552B IF + 8556A RF - 20Hz-300KHz - £400.
HP141T+ 8552B IF + 8555A 10 MC/S-18GHzS - £1000.
HP8443A Tracking Gen Counter 100KHz-110Mc/s - £200
HP8445B Tracking Preselector DC to 18GHz - £250.
HP8444A Tracking Generator • 5-1300Mc/s - £450.
HP8444A OPT 059 Tracking Gen • 5-1500Mc/s - £650.
HP35601A Spectrum Anz Interface - £300.
HP4953A Protocol Anz - £400.
HP8970A Noise Figure Meter + 346B Noise Head - £3k.
HP8755A+B+C Scalar Network Anz PI - £250 + MF 180C - Heads 11664 Extra - £150 each.
HP3709B Constellation ANZ £1,000.
HP11715A AM-FM Test Source - £350.
FARNELL TVS70MKII PU 0-70V 10 amps - £150.
MARCONI 6500 Network Scaler Anz - £500. Heads available to 40GHz many types in stock.
Mixers are available forANZs to 60GHz.
HP6131C Digital Voltage Source + -100V½ Amp.
HP5316A Universal Counter A+B.
Marconi TF2374 Zero Loss Probe - £200.
Racal/Dana 2101 Microwave Counter - 10Hz-20GHz - with book as new £2k.
Racal/Dana 1250-1261 Universal Switch Controller + 200Mc/s PI Cards and other types.
Racal/Dana 9303 True RMS Levelmeter + Head - £450.
TEKA6902A also A6902B Isolator - £300-£400.
TEK CT-5 High Current Transformer Probe - £250.
HP Frequency comb generator type 8406 - £400.
HP Sweep Oscillators type 8690 A+B + plug-ins from 20Mc/s to 18GHz also 18-40GHz.
HP Network Analyser type 8407A + 8412A + 8601A - 100Kc/s - 110Mc/s - £500 - £1000.
HP 8410-A-B-C Network Analyser 110Mc/s to 12 GHz or 18 GHz - plus most other units and displays used in this set-up - 8411a-8412-8413-8414-8418-8740-8741-8742-8743-8746-8650. From £1k.
Racal/Dana 9301A-9302 RF millivoltmeter - 1.5-2GHz - qty in stock £250-£400.
Racal/Dana Modulation Meter Type 9009-9008 - 8Mc/s - 1.5GHz - £150/£250 – 9009A £350.
Marconi RCL Bridge type TF2700 - £150.
Marconi Microwave 6600A 1 sweep osc., mainframe with 6650PI - 18-26.5 GHz or 6651 PI - 26.5-40GHz-£750 or PI only £600. MF only £250.
Gould J3B test oscillator + manual - £150.
Marconi 6155A Signal Source-1 to 2GHz - LED - £400.
Barr & Stroud Variable filter EF3 0.1Hz-100Kc/s + high pass + low pass - £150, other makes in stock.
Racal/Dana 9300 RMS voltmeter - £250.
HP 8750A storage normalizer - £400 with lead + S.A. or N, A
Marconi mod meters type TF2304 - £250 – TF2305 - £1,000.
Racal/Dana counters-99904-9905-9906-9915-9916-9917-9921-50Mc/s-3GHz - £100 - £400 - all fitted with FX standards.
HP180TR, HP181T, HP182T mainframes £300 - £500.
HP432A-435A or B-436A-power meters + powerheads to 60GHz - £150 - £1750 - spare heads available.
HP3586A or C selective level meter - £500.
HP86222A+B Sweep PI -01-2.4GHz + ATT £1000-£1250.
HP86290A+B Sweep PI-2 - 18GHz - £1000 - £1250.
HP8620C Mainframe - £250. IEEE £350.
HP8165A Programmable signal source - 1MHZ - 50Mc/s - £1k.
HP3455/3456A Digital voltmeter - £400.
HP5370A Universal time Interval counter - £1k.
HP5335A Universal counter - 200Mc/s-£1000.
HP3552A Transmission test set - £350.
TEKTRONIX 577 Curve tracer + adaptors - £900.
TEKTRONIX 1502/1503 TDR cable test set - £400.
HP8699B Sweep PI YIG oscillator .01 - 4GHz - £300. 8690B MF-£250. Both £500.
Dummy Loads & Power att up to 2.5 kilowatts FX up to 18GHz - microwave parts new and ex equipt - relays - attenuators - switches - waveguides - Yigs - SMA - APC7 plugs - adaptors etc. qty. in stock.
B&K Items in stock - ask for list.
Power Supplies Heavy duty + bench in stock - Farnell - HP - Weir - Thurlby - Racal etc. Ask for list. Large quantity in stock, all types to 400 amp - 100Kv.
HP8405A Vector voltmeter - late colour - £400.
HP8508A Vector voltmeter - £2500.
HP8505A Network Anz 500KHz-1.3GHz - £1000.
HP8505A + 8502A or 8503A test sets- £1200 - £1500.
HP8505A + 8502A or 8503A + 8501A normalizer - £1750-£2000.
Phillips 3217 50Mc/s oscilloscopes - £150-£250.
Phillips 3296 350Mc/s IR remote oscilloscope - £500.
R&S APN 62 LF S/G 0.1Hz – 260KHz with book - £500.
Wavetek-Schlumberger 4031 Radio communication test set

LIGHT AND OPTICAL EQUIPMENT
Anritsu ML93A & Optical Lead Power Meter - £250.
Anritsu ML93B & Optical Lead Power Meter - £350.
Power Sensors for above MA96A - MA98A - MA913A - Battery Pack MZ95A.
Anritsu MW97A Pulse Echo Tester.
PI available - MH914C 1.3 - MH915B 1.3 - MH913B 0.85 - MH925A 1.3 - MH929A 1.55 - MH925A 1.3GI - MH914C 1.3SM - £500 + one P.I.
Anritsu MW98A Time Domain Reflector.
PI available - MH914C 1.3 - MH915B 1.3 - MH913B 0.85 - MH925A 1.3 - MH929A 1.55 - MH925A 1.3GI - MH914C 1.3SM - £500 + one P.I.
Anritsu MZ100A E/O Converter.
+ MG912B (LD 1.35) Light Source + MG92B (LD 0.85) Light Source £350.
Anritsu MZ118A O/E Converter.
+MH922A 0.8 O/E unit + MH923 A1.3 O/E unit £350.
Anritsu ML96B Power Meter & Charger £450.
Anritsu MN95B Variable Att. 1300 £100.
Photo Dyne 1950 XR Continuous Att. 1300 - 1500 £100.
Photo Dyne 1800 FA. Att £100.
Cossor-Raytheon 108L Optical Cable Fault Locator 0-1000M 0-10kM £200.
TEK P6701 Optical Converter 700 MC/S-850 £250.
TEK OF150 Fibre Optic TDR – £750.
HP81512A Head 150MC/S 950-1700 £250.
HP84801A Fibre Power Sensor 600-1200 £250.

HP8158B ATT OPT 002+011 1300-1550 £300.
HP81519A RX DC-400MC/S 550-950 £250.
STC OFR10 Reflectometer – £250.
STC OFSK15 Machine jointing + eye magnifier – £250.

COMMUNICATION EQUIPMENT
Anritsu ME453L RX Microwave ANZ – £350.
Anritsu ME453L TX Microwave ANZ – £350.
Anritsu MH370A Jitter Mod Oscillator – £350.
Anritsu MG642A Pulse Patt Gen. £350.
System MS02A Timer & Digital Printer – £500.
Complete MS65A Error Detector.
Anritsu ML612A Sel Level Meter – £400.
Anritsu ML244A Sel Level Meter – £300.
W&G PCM3 Auto Measuring Set – £300.
W&G SPM14 Sel Level Meter – £300.
W&G SPM15 Sel Level Meter – £350.
W&G PS19 Level Gen – £500.
W&G DA20+DA1 Data ANZ £400.
W&G PMG3 Transmission Measuring Set – £300.
W&G PSS16 Generator – £300.
W&G PS14 Level Generator – £350.
W&G EPM-1 Plus Head Milliwatt Power Meter – £450.
W&G DLM3 Phase Jitter & Noise – £350
W&G DLM4 Data Line Test Set – £400.
W&G PS10 & PM10 Level Gen. – £250.

MISCELLANEOUS ITEMS
HP 3852A Data Acquisition Control Unit + 44721A 16ch input £1,000.
HP 4261 LCR meter – £650.
HP 4274 FX LCR meter – £1,500.
HP 4951A Protocol ANZ – £500.
HP 3488 Switch Control Unit + PI Boards – £500.
HP 75000 VXI Bus Controllers + E1326B-DVM-quantity.
HP 83220A GSM DCS/PCS 1805-1990MC/S convertor for use with 8922A – £2,000.
HP 1630-1631-1650 Logic ANZ's in stock.
HP 8754A Network ANZ 4-1300MC/S + 8502A + cables – £1,500.
HP 8754A Network ANZ H26 4-2600MC/S + 8502A + Cables – £2,000.
HP 8350A Sweeper MF + 83540A PI 2-8.4GHZ + 83545A PI 5.9-12.4GHZ all 3 – £3,500.
HP MICROWAVE TWT AMPLIFIER 489A 1-2GHZ-30DB – £400.
HP PREAMPLIFIER 8447A 0.1-400MC/S – £200. Dual – £300.
HP PREAMPLIFIER 8447D 0.01-1.3GHZ – £400.
HP POWER AMPLIFIER 8447E 0.01-1.3GHZ – £400.
HP PRE + POWER AMPLIFIER 8447F 0.01-1.3GHZ – £500.
HP 3574 Gain-Phase Meter 1HZ-13MC/S OPT 001 Dual – £400.
MARCONI 2305 Modulation Meter-50KHZ-2.3 GHZ – £1,000.
MARCONI 2610 True RMS Meter – £450.
MARCONI 893B AF Power Meter (opt Sinad filter) – £250-£350.
MARCONI 6950-6960B Power Meters + Heads – £400-£900.
MARCONI SIGNAL SOURCE-6055-6056-6057-6058-6059 – FX Range 4-18GHZ– £250-£400.
RACAL 1792 COMMUNICATION RX – £500 early – £1,000 – late model with back lighting and byte test.
RACAL 1772 COMMUNICATION RX – £400-£500.
PLESSEY PR2250 A-G-H COMMUNICATION RX – £500-£900.
TEK MODULE MAINFRAMES – TM501-502-503-504-506-TM5003-5006.
TEK PI 5010-M1 – Prog Multi Interface – £250. FG Prog 20MC/S Function Gen – £400 – S1 Prog Scanner – £250 – DM Prog DMM – £400.
TEK 7000 OSCILLOSCOPE MAINFRAMES – 7603-7623-7633-7834-7854-7904-7904A-7104 – £150-£1,000.
TEK 7000 PI's – 7A11-7A12-7A13-7A18-7A19-7A22-7A24-7A26-7A29-7A42-7B10-7B15-7B53A-7B80-7B85-7B92A-7D15-7D20.
TEK 7000 – 7S11-7S12-7S14-7M11-S1-S2-S3A-S4-S5-S6-S51-S53-S54.
HP POWER SUPPLIES – 6621A-6623A-6624A-6632A-6652A. Qtys available. Also 6000 types £POA.

RADIO COMMUNICATION TEST SETS
BULK PURCHASE ONLY FROM JOHNS RADIO
HP 8920A RF Communication Test Sets – Opts available 001-3-4-5-7-11-12-14-H13-K13. £1,500-£1,700.
HP8920A with opt 002 Spectrum anz plus tracking generator plus opts. 001-3-4-5-11-12-014 available in part includes syn sig generator - digital oscillioscope distortion meter - mod meter - RF power meter etc. £2,500.
MOTOROLA R2600A plus RLN4260A RF Test Set – £3,000.
MARCONI 2955 RF Test Sets-1000MC/S – £1,200 each.
MARCONI 2958 RF Test Sets-1000MC/S – £1,300 each.
MARCONI 2960 RF Test Sets-1000MC/S – £1,400 each.
MARCONI 2955A RF Test Sets-1000MC/S – £2,000 each.
MARCONI 2960A RF Test Sets-1000MC/S – £2,000 each.
ANRITSU MS555A2 Radio Comm Anz-1000M/Cs – £1,200 each.
MARCONI 2019A SYNTHESIZED SIGNAL GENERATORS – 80KC/S-1040MC/S – AM-FM all functions tested off the pile as received from Gov – in average used condition – £650 each or in original Gov cartons 1st class condition each fitted with IEEE plus added protection front cover lid containing RF-IEEE-mains cables + N to BNC adaptor – Attenuator etc. + Instruction Book – fully checked to high standards in our own workshop – £1k.
MARCONI 2022E SYNTHESIZED SIGNAL GENERATOR – 10KC/S-1.01GHZ AM-FM – made small and light for portability being the naval version – all functions tested off the pile as received from Gov – in average used condition – £1,000 each or in original Gov cartons as new condition – each fitted with IEEE + added protection front cover lid containing RF-IEEE – mains cables-N to BNC Adaptor – Attenuator-50-75OHM adaptor etc. + Instruction Book – fully checked to high standards in our own workshop – £1,250 each.
WE KEEP IN STOCK HP and other makes of RF Frequency doublers which when fitted to the RF output socket of a S/Generator doubles the output frequency EG.50-1300MC/S to 50-2600MC/S price from £250 – £450 each.

SPECTRUM ANALYZERS
HP 3580A 5HZ-50KHZ – £750.
HP 3582A Dual 0.2HZ-25.5KHZ – £1,500.
HP 3585A 20HZ-40MC/S – £3,500.
HP 3588A 10HZ-150MC/S – £7,500.
HP 8568A 100HZ-1.5GHZ – £3,500.
HP 8568B 100HZ-1.5GHZ – £4,500.
HP 8590B 9KC/S-1.8GHZ – £4,500.
HP 8569B 10MC/S (0.01-22GHZ) – £3,500.
HP 3581A Signal Analyzer 15HZ-50KHZ – £400.
TEK491 10MC/S-12.4GHZ + 12.4-40GHZ – £500.
TEK492 50KHZ-21GHZ OPT 2 – £2,500.
TEK492P 50KHZ-21GHZ OPT 1-2-3 – £3,500.
TEK492AP 50KHZ-21GHZ OPT 1-2-3 – £4,000.
TEK492BP 50KHZ-21GHZ – £3,000-£4,000.
TEK495 100KHZ-1.8GHZ – £2,000.
HP 8557A 0.01MC/S-350MC/S – £500 + MF180T or 180C – £150 – 182T – £500.
HP 8558B 0.01-1500MC/S – £750 – MF180T or 180C – £150 – 182T – £500.
HP 8559A 0.01-21GHZ – £1,000 – MF180T or 180C – £150 – 182T – £500.
HP 8901A AM FM Modulation ANZ Meter – £800.
HP 8901B AM FM Modulation ANZ Meter – £1,750.
HP 8903A Audio Analyzer – £1,000.
HP 8903B Audio Analyzer – £1,500.
MARCONI 2370 SPECTRUM ANALYZERS – HIGH QUALITY – DIGITAL STORAGE – 30HZ-110MC/S Large qty to clear as received from Gov – all sold as is from pile complete or add £100 for basic testing and adjustment – callers preferred – pick your own from over sixty units – discount on qtys of five.
A EARLY MODEL GREY – horizontal alloy cooling fins – £200.
B LATE MODEL GREY – vertical alloy cooling fins – £300.
C LATE MODEL BROWN – as above (few only) – £500.

OSCILLOSCOPES
TEK 465-465B 100MC/S + 2 probes – £250-£300.
TEK 466 100MC/S storage + 2 probes – £200.
TEK 475-475A 200MC/S-250MC/S + 2 probes – £300-£350.
TEK 2213-2213A-2215-2215A-2224-2225-2235-2236-2245-60-100MC/S – £250-£400.
TEK 2445 4ch 150MC/S + 2 probes – £450.
TEK 2445A 4ch 150MC/S + 2 probes – £600.
TEK 2445B 4ch 150MC/S + 2 probes – £750.
TEK 468 D.S.O. 100MC/S + 2 probes – £500.
TEK 485 350MC/S + 2 probes – £550.
TEK 2465 4ch-300MC/S – £1,150.
TEK 2465A 4ch-350MC/S – £1,550.
TEK 2465ACT 4ch-350MC/S – £1,750.
TEK D.S.O. 2230 -100MC/S + 2 probes – £1,000.
TEK D.S.O. 2430 -150MC/S + 2 probes – £1,250.
TEK D.S.O. 2430A -150MC/S + 2 probes – £1,750.
TEK D.S.O. 2440 -300MC/S + 2 probes – £2,000.
TEK TAS 475-485 -100MC/S-20MC/S 4 ch + 2 probes – £900-£1.1K.
HP1740A – 100MC/S + 2 probes – £250.
HP1741A – 100MC/S storage + 2 probes – £200.
HP1720A – 1722A - 1725A - 275MC/S + 2 probes – £300-£400.
HP1744A – 100MC/S storage - large screen – £250.
HP1745A – 1746A - 100MC/S - large screen – £350.
HP54100A – 1GHz digitizing – £500.
HP54200A – 50MC/S digitizing – £500.
HP54501A – 100MC/S digitizing – £500.
HP54100D – 1GHZ digitizing – £1,000.

MICROWAVE COUNTERS – ALL LED READOUT
EIP 351D Autohet 20Hz-18GHz – £750.
EIP 371 Micro Source Locking – 20Hz-18GHz – £850.
EIP 451 Micro Pulse Counter – 300MC/S-18GHz – £700.
EIP 545 Microwave Frequency Counter – 10Hz-18GHz – £1K.
EIP 548A Microwave Frequency Counter – 10HZ-26.5GHz – £1.5k.
EIP 575 Microwave Source Locking – 10Hz-18GHz – £1.2K.
EIP 588 Microwave Pulse Counter – 300MC/S-26.5GHz – £1.4K.
SD 6054B Micro Counter 20HZ-24GHZ – SMA Socket – £800.
SD 6054B Micro Counter 20HZ-18GHZ – N Socket – £700.
SD 6054D Micro Counter 800MC/S-18GHz – £600.
SD 6246A Micro Counter 20Hz-26GHz – £1.2K.
SD 6244A Micro Counter 20Hz-4.5GHz – £400.
HP5352B Micro Counter OPT 010-005-46GHz – new in box – £5k.
HP5340A Micro Counter 10HZ-18GHz – Nixey – £500.
HP5342A Micro Counter 10HZ-18-24GHz – £800 -£1K – OPTS 001-002-003-005-011 available.
HP5342A + 5344S Source Synchronizer – £1.5K.
HP5345A 500MC/S 11 Digit LED Readout – £400.
HP5345A + 5354A Plugin – 4GHz – £700.
HP5345A + 5355A Plugin with 5356A 18GHz Head – £1K.
HP5385A 1GHz 5386A-5386A 3GHz Counter – £1K-£2K.
Racal/Dana Counter 1991-160MC/S – £200.
Racal/Dana Counter 1992-1.3GHz – £600.
Racal/Dana Counter 9921-3GHz – £350.

SIGNAL GENERATORS
HP8640A – AM-FM 0.5-512-1024MC/S – £200-£400.
HP8640B – Phase locked – AM-FM-0.5-512-1024MC/S – £500-£1.2K. Opts 1-2-3 available.
HP8654A – B AM-FM 10MC/S-520MC/S – £300.
HP8656A SYN AM-FM 0.1-990MC/S – £900.
HP8656B SYN AM-FM 0.1-990MC/S – £1.5K.
HP8657A SYN AM-FM 0.1-1040MC/S – £2K.
HP8657B SYN AM-FM 0.1-2060MC/S – £3K.
HP8660C SYN AM-FM-PM-0.01-1300MC/S-2600MC/S – £2K.
HP8660D SYN AM-FM-PM-0.01-1300MC/S-2600MC/S – £3K.
HP8673D SYN AM-FM-PM-0.01-26.5 GHz – £12K.
HP3312A Function Generator AM-FM 13MC/S-Dual – £300.
HP3314A Function Generator AM-FM-VCO-20MC/S – £600.
HP3325A SYN Function Generator 21MC/S – £800.
HP3325B SYN Function Generator 21MC/S – £2K.
HP8673-B SYN AM-FM-PH 2-26.5 GHz – £6.5K.
HP3326A SYN 2CH Function Generator 13MC/S-IEEE – £1.4K.
HP3336A-B-C SYN Func/Level Gen 21MC/S – £400-£300-£500.
Racal/Dana 9081 SYN S/G AM-FM-PH-5-520MC/S – £300.
Racal/Dana 9082 SYN S/G AM-FM-PH-1.5-520MC/S – £400.
Racal/Dana 9084 SYN S/G AM-FM-PH-.001-104MC/S – £300.
Racal/Dana 9087 SYN S/G AM-FM-PH-.001-1300MC/S – £1K.
Marconi TF2008 AM-FM-Sweep 10KC/S-510MC/S – £200 Fully Tested to £300, as new + book + probe kit in wooden box.
Marconi TF2015 AM-FM-10-520MC/S – £100.
Marconi TF2016A AM-FM 10KC/S-120MC/S – £100.
Marconi TF2171/3 Digital Synchronizer for 2015/2016A – £50.
Marconi TF2018A AM-FM SYN 80KC/S-520MC/S – £500.
Marconi TF2019A AM-FM SYN 80KC/S-1040MC/S – £650-£1K.
Marconi TF2022E AM-FM SYN 10KC/S-1.01GHz – £1K-£1.2K.
R & S SMPD AM-FM-PH 5KHz-2720MC/S – £3K.
Anritsu MG3601A SYN AM-FM 0.1-1040MC/S – £1.2K.

ITEMS BOUGHT FROM HM GOVERNMENT BEING SURPLUS. PRICE IS EX WORKS. SAE FOR ENQUIRIES. PHONE FOR APPOINTMENT OR FOR DEMONSTRATION OF ANY ITEMS, AVAILABILITY OR PRICE CHANGE. VAT AND CARRIAGE EXTRA. ITEMS MARKED TESTED HAVE 30 DAY WARRANTY. WANTED: TEST EQUIPMENT-VALVES-PLUGS AND SOCKETS-SYNCROS-TRANSMITTING AND RECEIVING EQUIPMENT ETC.

Johns Radio, Whitehall Works, 84 Whitehall Road East, Birkenshaw, Bradford BD11 2ER. Tel: (01274) 684007. Fax: 651160

CIRCLE NO. 124 ON REPLY CARD

Hands-on Internet

Cyril Bateman has been looking at what's available on the net for helping you measure current, large or small, AC or DC.

Measurement of current, whether DC or AC, is simple provided its amplitude and frequency is within the capabilities of your digital multimeter. But close examination of your multimeter's specifications might reveal it to have serious limitations.

Of course if you possess a suitably accurate, non-inductive resistor that can be used to convert current into a voltage, your measurement capabilities could be enhanced. Unfortunately though, when AC even at modest frequencies has to be measured, ensuring measurement accuracy can be difficult. Most multimeters having a restricted capability and almost all resistors are inductive.

For most circuit measurements, small 'clip-on' oscilloscope current probes can be used. For occasional use, you could even hand-wind a small ferrite toroid.[2]

With increasing current, conversion to voltage using resistors can generate considerable heat. If an alternating current is to be measured, this heat can be avoided by using a suitable current transformer.

At low frequencies, economical transformers are readily available to handle currents in excess of 100A while providing a voltage output suitable for a 200mV DMM.

Transformers designed to measure very high currents at very high frequencies are also available from specialist suppliers. One common use for

Information sources

1. W32/ExploreZip.worm
http://www.avertlabs.com/public/datafiles/valerts/vinfo/va10185.asp
2. Probing for switching losses — A,Durrant, G.Whitfield, *Electronics World* October 1995
3. National Semiconductors — http://www.national.com
4. Burr-Brown Corporation — http://www.burr-brown.com
5. Linear Technology Corporation — http://www.linear-tech.com
6. Maxim Integrated Products — http://www.maxim-ic.com

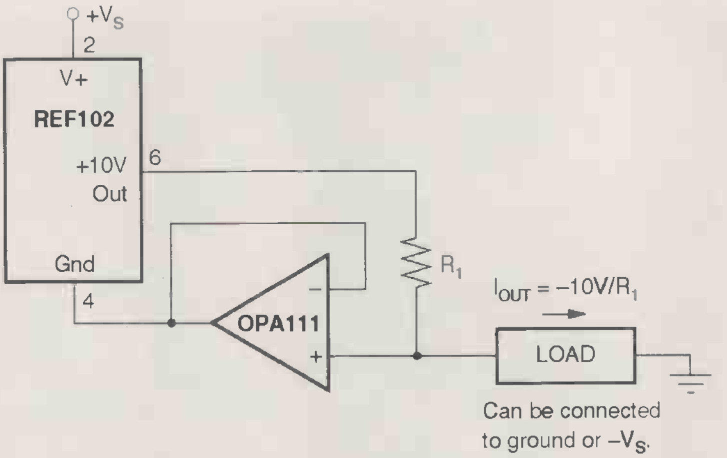


Fig. 1. AN-002 carries the sub-title How to make the most accurate current source. Long term tests of fifteen samples claimed the band-gap reference used in this simple circuit, measured better than 5ppm stability at 1000 hours.

them is to measure equipment power line EMC levels without disturbing the circuit. Such high frequency, high current transformers are expensive though.

In the March issue I looked at several methods for providing measurements of voltage with extended frequency and dynamic voltage ranges. These included rms as well as average responding circuits. These circuits could also be used to measure current, assuming that it is first precisely converted into a suitable voltage.

Whether you are measuring direct or alternating current, some means of generating an accurate, repeatable current will be needed to allow you to calibrate or checking your instruments.

Generating test currents

One extremely simple and reliable way I have long used to generate a consistent DC current relies on using a known fixed resistor connected between the adjustment pin and the output pin of an *LM117/317* adjustable voltage regulator integrated circuit.

This simple circuit is described in a datasheet.[3] In practice, I permanently mounted three resistors in series, using an *LM317K* mounted on a heatsink, to provide stable, selectable 0.1A, 0.5A and 1A direct-current references.

These currents prove ideal when I need to measure resistances that are too small for my multimeter to measure. I simply pass a current through the unknown resistance, then measure the voltage developed across the unknown to provide a simple, four terminal and accurate measurement of resistance, down to just a few milliohms. Other members of this family can be used to provide lower and higher currents.

The first time I used such a high-current system was to provide a consistent and temperature stable, 27.5A DC, regardless of load resistance changes. This current was required to power a 1000 hours elevated temperature and load endurance test of some

Bugs

On 10 June, Intel, Microsoft and many other big corporations, closed down large sections of their e-mail networks, in an attempt to limit the spread of the latest and most damaging Internet virus. This virus spreads by sending e-mail messages to users, with an attached file 'zipped_files.exe'. If this attachment is opened, it attacks 32-bit Windows systems by deleting files from the hard disk.

This virus – or more accurately this worm since it spreads by piggy-backing any MAPI compliant e-mail system – is called W32/ExploreZip.worm. It is believed to have originated from Israel, but spread very quickly to all Internet using countries.

If you send an e-mail to an infected system, you can receive a response which uses your original message header, and a text which responds, "Hi <your name>, I received your e-mail and I shall send you a reply ASAP. Till then, take a look at the attached zipped docs. Bye".

If you open this attachment, a program runs while an error message is displayed. This program immediately searches your hard-disk drive and overwrites all files with .c, .cpp, .h, .asm, .doc, .xls, or .ppt extensions, reducing them to zero bytes long. It copies itself as 'Explore.exe' into Windows/System and modifies WIN.INI so it is run every time Windows is started. Any e-mail you now send, can be infected.[1]

This virus combines the reproductive capabilities of the Melissa worm with the destructive force of the Chernobyl virus. It has been given a severity rating of 7 out of 10, by Network Associates, because of its ability to seriously damage 32-bit Windows systems, and even MACs if they are running a suitable PC emulator.

Fig.A. Probably the most dangerous Internet virus to date. With many servers out of action, Internet was almost unusable for several days following the initial attacks.

EMC filter components.

A high-precision source of DC requires a precision voltage reference. Burr Brown publishes details of the long-term stability obtained using the *REF102*. This is a 10V precision reference with an op-amp to compare its voltage with that dropped across a precision resistor.

Full details of this reference can be found in publication AB-002C, which can be downloaded,[4] **Fig. 1**.

Providing a known, stable and repeatable source of alternating current is more difficult. While developing an LCD backlight generator some years ago, Jim Williams of Linear Technology used a Tektronix current probe with a custom wideband amplifier to perform circuit measurements. The combination provided a 0.1dB error bandwidth from 20kHz to 10MHz.

To quantify his measurements, Jim needed an easily calibrated source of 10mA at 60kHz. He built a an amplitude-stabilised output stage with a Wien bridge oscillator, using five op-amps. Output current from this circuit was adjusted to develop exactly 1.00V RMS across a 100Ω 0.1% resistor. This circuit is described in 'Design Note 101' from Linear Technology.[5]

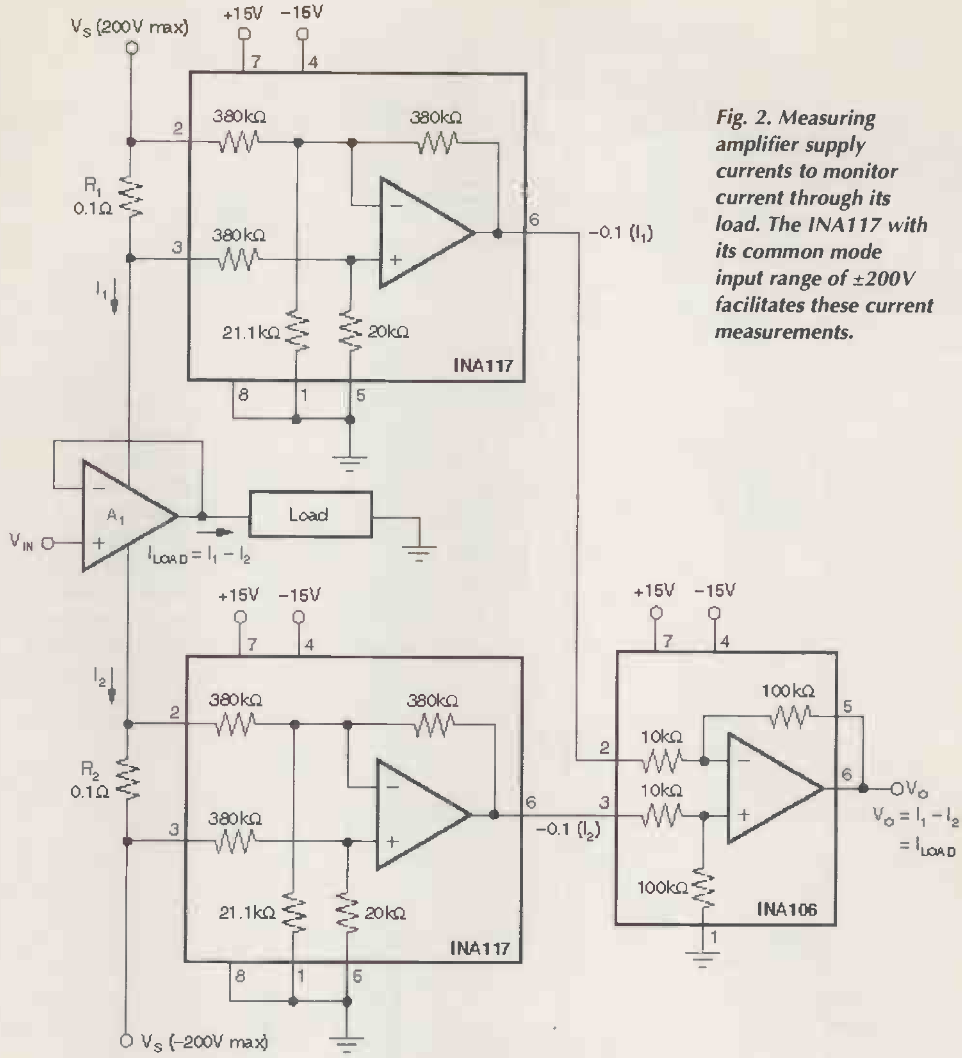


Fig. 2. Measuring amplifier supply currents to monitor current through its load. The INA117 with its common mode input range of ±200V facilitates these current measurements.

Application circuits

Burr-Brown's 29-page application note AB-165 titled 'Implementation and Applications of Current Sources and Current Receivers'[4] provides a good introduction to many techniques for measuring and generating known currents.

Perhaps even more useful are the note's many circuits using these techniques. One I particularly liked was a circuit for monitoring load currents of a power amplifier. This uses the *INA117* difference amplifier to convert the rail currents to voltages and can support amplifier supply rails up to ±200V, **Fig. 2**.

When you need an integrated amplifier to work with a current input, one option is to first convert these currents into a measurable voltage. Alternatively you could consider using an amplifier with a 'Norton' input. A Norton op-amp is able to pass current between its positive and negative inputs.

One of the first Norton amplifiers marketed was the *LM3900* from National Semiconductors.[3] This provides four current-differencing amplifiers in a 14-pin package.

The company's 1972 introductory application note, AN-72, provides many special circuits that use the unique properties of a Norton amplifier.

Being current operated a Norton amplifier is happy using input resistors much larger than a megohm. This is illustrated in the simple circuit shown, which provides four voltage programmable current sources using one integrated circuit, **Fig. 3**.

A high-accuracy voltage programmable current source using two

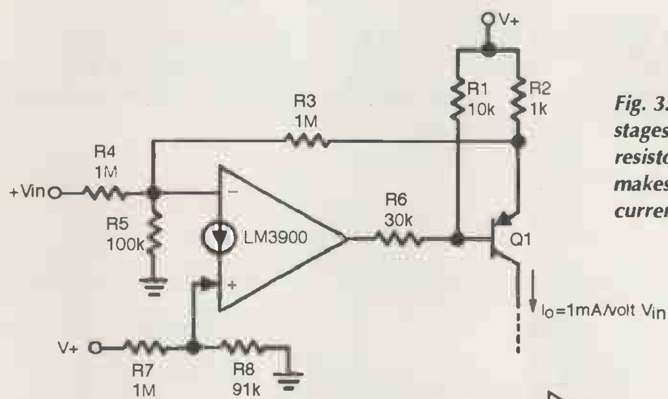


Fig. 3. With its current-mirror input stages and using high value input resistors, this quad 'Norton' amplifier makes multiple voltage programmable current sources in a small board area.

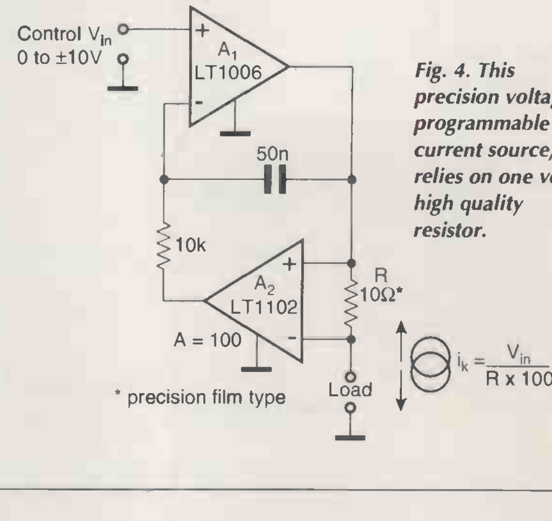


Fig. 4. This precision voltage programmable current source, relies on one very high quality resistor.

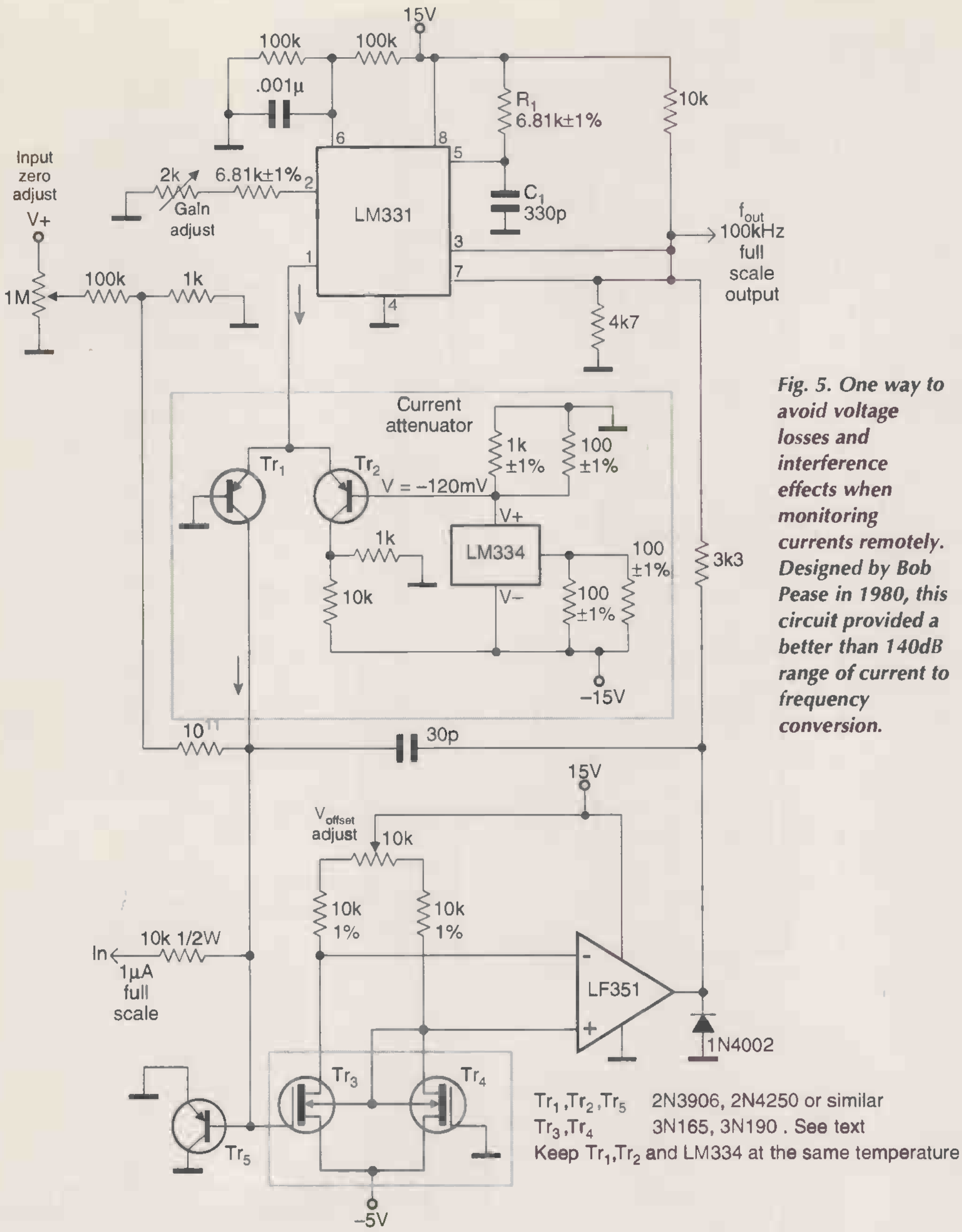


Fig. 5. One way to avoid voltage losses and interference effects when monitoring currents remotely. Designed by Bob Pease in 1980, this circuit provided a better than 140dB range of current to frequency conversion.

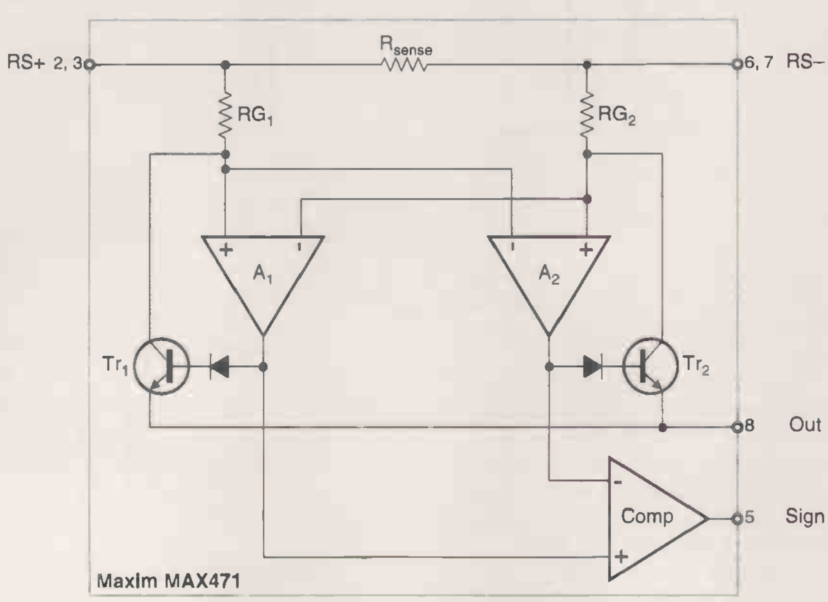


Fig. 6. Up to date method of monitoring DC currents into and out of supply batteries. Status of the SIGN output pin indicates direction of current flow.

integrated circuits is detailed in Linear Technology's application note AN-45. Entitled 'Measurement and control circuit collection'. Its page 7 has an oscilloscope display showing this circuit's clean response to a square wave input, **Fig. 4**.

The *LT1102* amplifier used has a 0.05% gain specification and 5ppm temperature coefficient, so in practice the circuit's linearity of output current is determined by the quality of its 10Ω sense resistor.

Current-to-frequency

Perhaps you need to monitor currents at a remote location, but interference degrades accuracy when this current is converted into a voltage.

In National's application note AN 240, Bob Pease described a number of circuits suitable for converting current into a variable frequency signal.[3]

Since frequency now replaces current amplitude, it is not subject to interference or loss of accuracy due to voltage dropped on long cables. The circuit shown offers a 140dB dynamic range, with input currents from picoamps to microamps. It provides an easily measured output of 100kHz for a 1μA input, **Fig. 5**.

Monitoring battery charge

The present escalation in portable rechargeable battery-powered equipment highlights the need to monitor battery status and charging currents.

To avoid degrading earth-path continuity, it is preferable to monitor currents in the high-side supply line. If the monitoring circuit is powered from the same battery this then presents a common mode input voltage equal to the circuit's positive supply voltage.

Maxim provides two versions of their unique dedicated high-side current monitoring circuits.[6] The *MAX471* provides a built in 35 mOhms current sense resistor suitable for currents up to 3A. The *MAX472* uses external resistors for sense, $RG_{1,2}$, and these can be scaled for larger currents.

Both versions operate in a similar way. Depending on the direction the monitored current flows, either Tr_1 or Tr_2 turns on, but not both at once. Output current from the emitter of the active transistor flows to ground via a suitable outboard resistor connected to the output pin. This resistor develops the output voltage. The value of the resistor sets the desired input current/output voltage scale factor.

Direction of the monitored current flow is indicated by the state of the SIGN output terminal, which is an open-collector logic output, **Fig. 6**. ■

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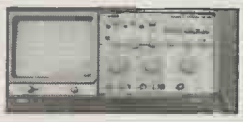

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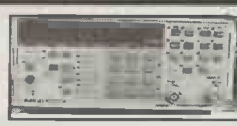

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Stand-alone event logger

This compact, battery-operated unit wakes up for a preprogrammed period and records events, together with a time stamp, into an 8K EEPROM. It then plugs into a PC so that its data can be off-loaded, after which it is made ready to go again.

Designed by Pei An and Pinhua Xie.

An event logger is a device that records a time stamp when an event occurs. It has many applications. In a supermarket for example, the device, together with a light interrupt sensor, can record the number of customers entering the premises, and when they entered. From the records of time stamps, shop managers can find out how many people are shopping throughout the day and determine peak selling times.

The event could also be a flash of light, a burst of sound, a movement, etc. Almost any event can be logged, given a suitable sensor to convert the physical event into an electrical signal that can then trigger the event logger.

A stand-alone event logger is a dedicated device. Its only task is to log events and save time stamps into memory. While logging events, it needs no external connections other than the sensor and any necessary signal conditioning circuitry.

The one described here off-loads its data to a PC when all the desired events have been logged. This allows the logged data to be analysed and permanently stored. The unit can be made very compact and has ultra low power consumption.

The logger, **Fig. 1**, is Pic based. It has one event input channel. An event is recognised as the low-to-high transition of the input signal. Whatever sensor is used needs to have a ttl output or a simple switch action capable of pulling the event-channel input low when closed.

On-board memory allows up to 1100 events to be recorded. A PP3 9V battery provides power.

Operating the logger

The data logger has three operation modes: initialisation mode, event-logging mode and data-downloading mode.

During initialisation, the device plugs into a host PC via the

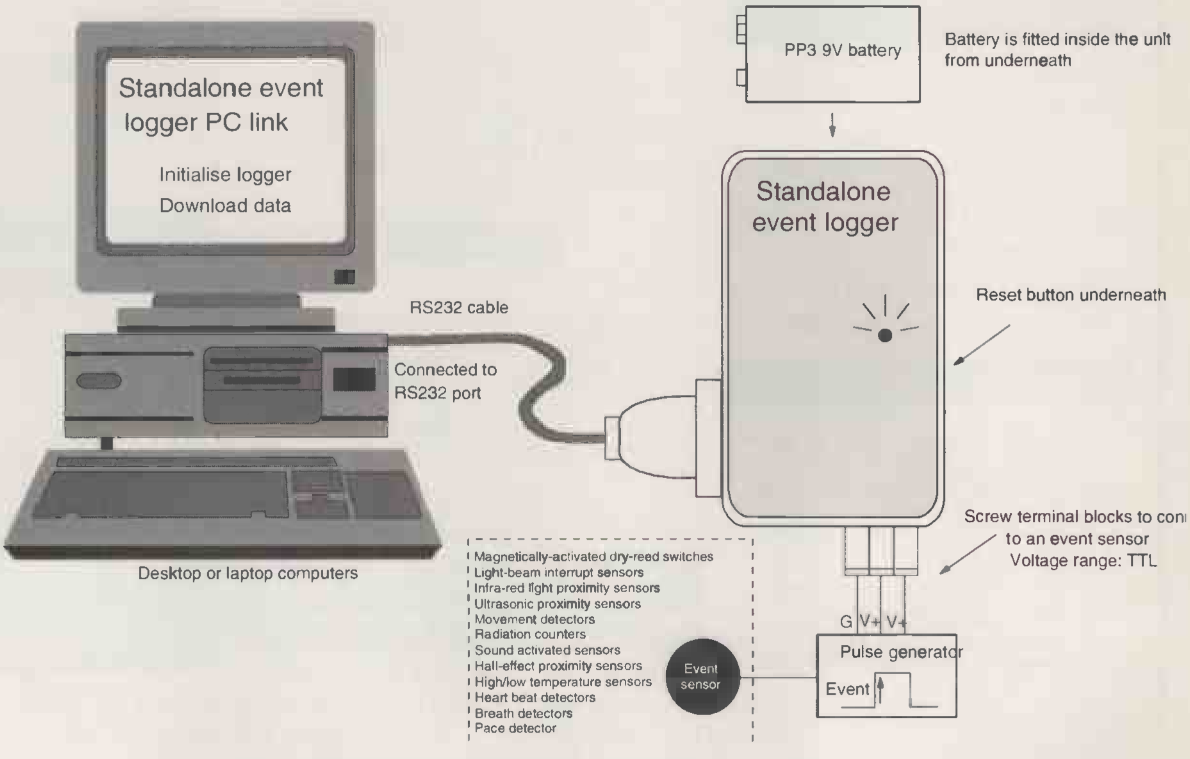


Fig. 1. A stand-alone event logger is used to acquire event from the external world. The logger connects to host PC via the RS232 port for initial configuration. After that it is disconnected from the PC and placed in a designated location to acquire event. After the data acquisition session is completed, the logger is connected to the host PC again for data downloading. A low-to-high transition is recognised as an event trigger. A sensor, amplification and signal shaping circuits are required to form a complete system.

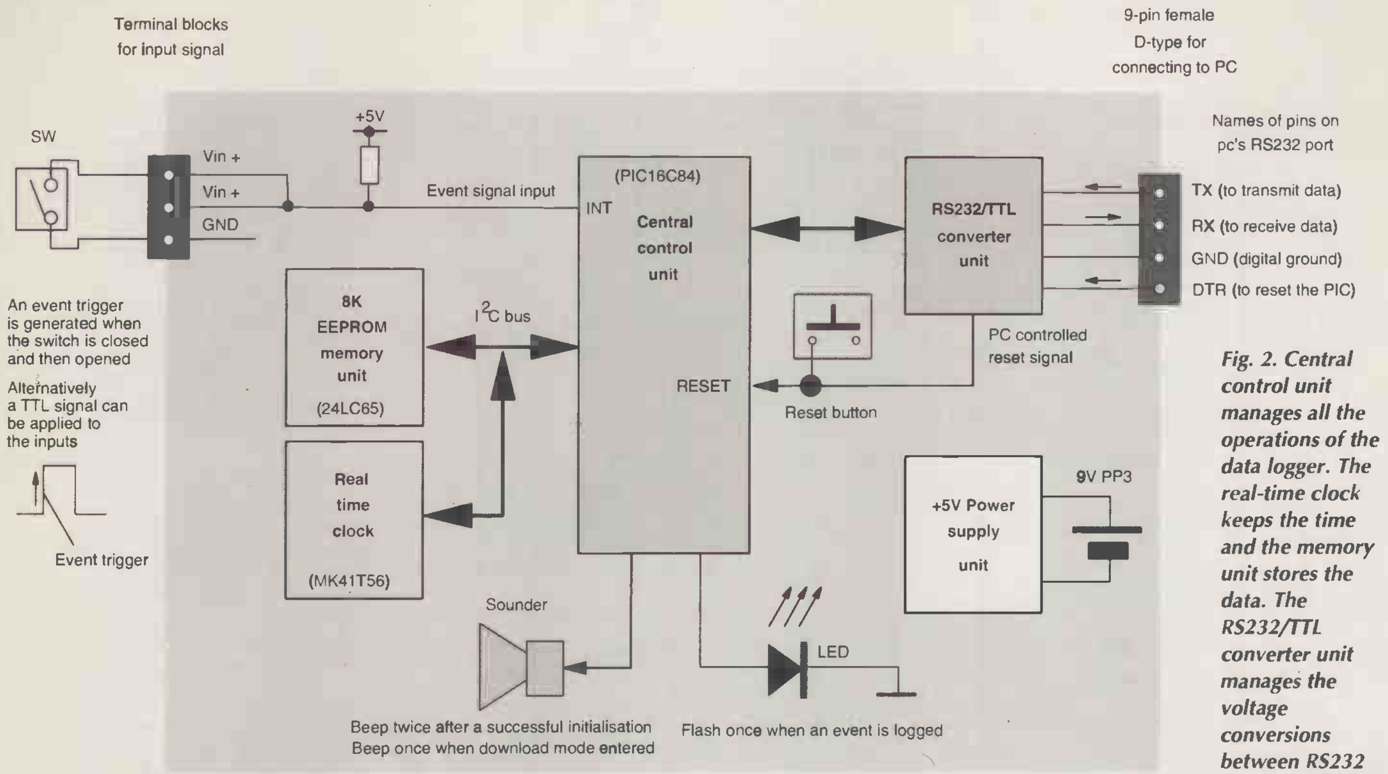


Fig. 2. Central control unit manages all the operations of the data logger. The real-time clock keeps the time and the memory unit stores the data. The RS232/TTL converter unit manages the voltage conversions between RS232 and TTL logic level.

RS232 port using a standard serial cable. The operator specifies a launch time in a PC-to-Pic link program running on the PC. After initialisation, the event logger enters its data-logging mode. The logger is then disconnected from the PC and placed where the events occur.

After the launch time is reached, at each event received, the logger stores a time stamp comprising the year, month, day, day of week, hour, minute and second in its memory.

When the logging session is ended, the event logger is plugged to the host PC again for data downloading. The time stamps stored in the memory are transferred into the PC.

Hardware details

The block diagram of the event logger is given in **Fig. 2**. The system comprises five units. They are a central control unit, a memory unit, a real time clock, an RS232/TTL converter and a power supply unit. The complete circuit diagram is given in **Fig. 3**.

The system uses only three key ICs: a *24LC65* 8Kbyte EEPROM, a *PIC16C84* controller and an *MK41T56* real time clock. The 8Kbyte EEPROM and the real-time clock communicate with the Pic via an I^2C bus. You will find more details of the I^2C bus in the first two references in the 'More information' panel.

The *PIC16C84* manages responses to the incoming event signal and stores time stamps in the memory. It also controls communication with a PC via the RS232 port.

This logger has a number of user-friendly features. These depend on how you write the software to control the logger of course, but my software is available for those of you who do not want to write your own. Details are given later.

An on-board piezo-electric sounder produces short bursts of sound if the logger receives a command from the PC successfully. The on-board led flashes if an event is detected. When the device is connected to a PC, resetting of the Pic is performed automatically by the PC.

The event signal input connects to the INT interrupt input of the *PIC16C84*. The INT pin is pulled to a logic high state internally. So a simple switch can be used to generate the required event signal as it is first closed and then opened. Alternatively, an external trigger signal having a TTL voltage level can be used.

Table 1. Functions of i/o pins on the 16C84 controller.

Port	Name	Pin	Function
A	RA0	17	serial data out from Pic – connects to Rx of pc's RS232 port
A	RA1	18	serial data Input to Pic – connects to Tx of pc's RS232 port)
A	RA2	1	not used
A	RA3	2	not used
A	RA4	3	not used
B	RB0	6	event signal input – Pic generates interrupt at low-to-high transition
B	RB1	7	control of the sounder – output
B	RB2	8	control of the LED – output
B	RB3	9	I^2C bus serial clock (SCL) for memory and clock (output)
B	RB4	10	I^2C bus serial data (SDA) for memory and clock (i/o)

Table 2. Addresses within the real-time clock.

Address	Function	Bits (bcd)	Value range
0	second register	0-6	00-59
1	minute register	0-6	00-59
2	hour register	0-5	00-23
3	day register	0-2	01-07
4	date register	0-5	01-31
5	month register	0-4	01-12
6	year register	0-7	00-99
7	control register		
9-64	RAM		

Bit functions of the control register from bit 7 to bit 0 are defined thus.

Bit	Function
7	Output control, 0 or 1
6	Frequency test bit (bit 6=4, output test frequency)
5	Sign bit
4-0	Unused

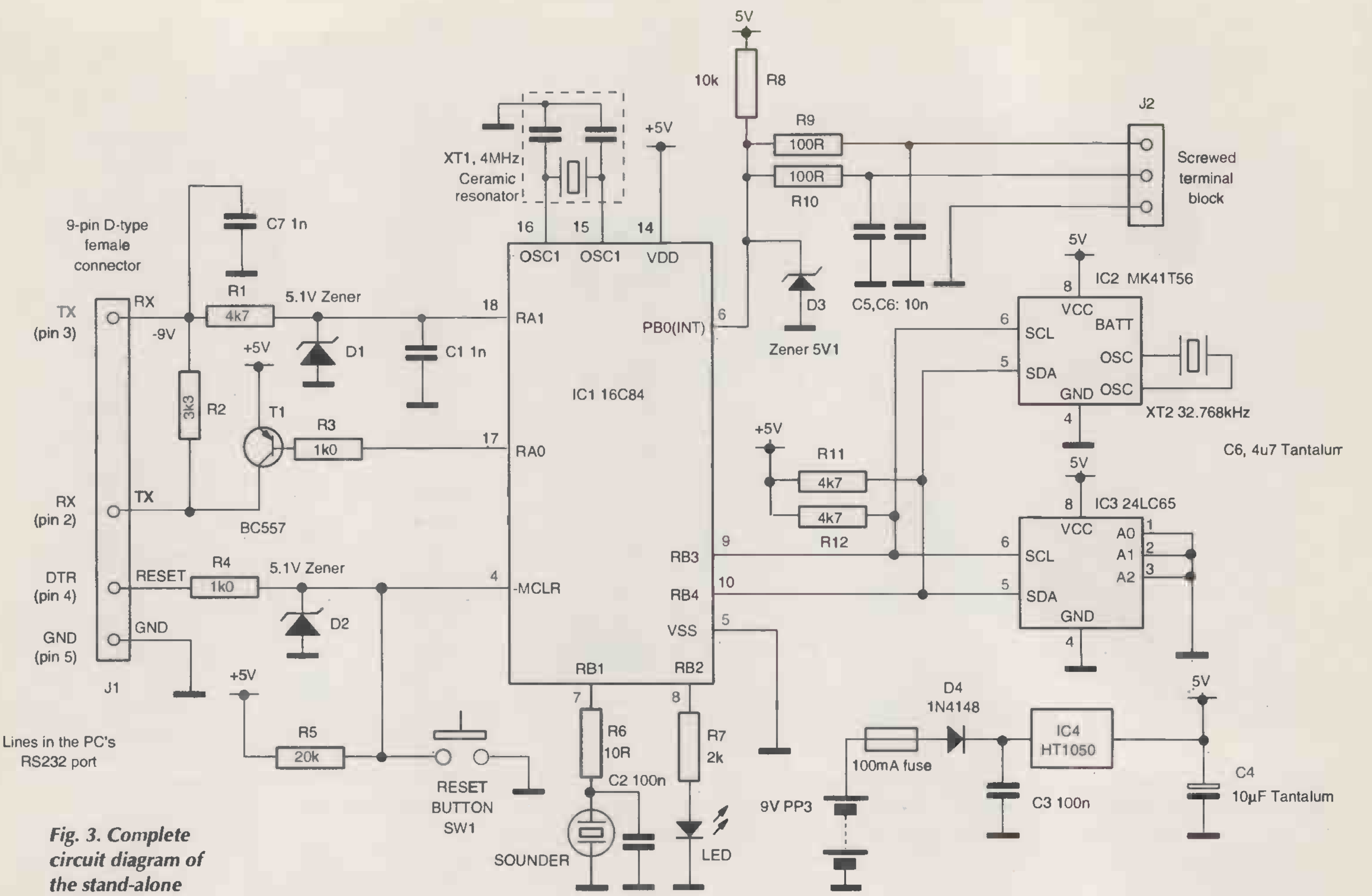


Fig. 3. Complete circuit diagram of the stand-alone data logger. A PIC16C84, a 41T56 timekeeper and a 24LC65 8kbyte EEPROM are involved. The circuit can be constructed on a single-sided PCB board and housed in a compact ABS box.

Central control

The central control unit revolves around a Microchip *PIC16C84* peripheral-interface controller. It has an electrically-erasable memory to store program, making it particularly useful for product development, **Fig. 4**. Details of the *PIC16C84* can be found in the third item in the 'More information' panel.

In this design, the Pic works in its crystal oscillator mode and its clock is governed by a 4MHz ceramic resonator. Input/output lines of the Pic are used as in **Table 1**.

Real-time clock

The *MK41T56* real-time clock is a low-power timekeeper that contains a 512 bit static CMOS RAM block organised as 64 words by 8 bits. The first eight bytes are registers storing time and date. Communication is via I²C bus, the device acting as a slave.

This clock continually monitors V_{cc}. If this voltage falls below a certain threshold, the device terminates data transfer. This is to prevent erroneous data from being written to the device. The battery could be a 3V 30mAh lithium cell. Typical data retention period is in excess of 10 years.

Figure 5 shows the pin-out and internal block diagram of the *MK41T56*. The device consumes 3mA when active. Standby current, when SDA and SCL are both high, is 1μA.

Pins OSC0 and OSC1 connect to a 32.768MHz crystal. SCL is the clock line of the I²C bus and SDA is the bi-directional data line. FT/OUT is the frequency test output. Functions of time registers within the 64 byte memory are shown in **Table 2**.

Data is written to or read from the *41T56* via the I²C bus. Write operations set up the time and date while read operations retrieve the time, **Fig. 6**.

Following a start condition on the I²C bus, an eight-bit slave address is clocked into the device from the master transmitter. The slave address from bit 7 to bit 0 has the following format: 1, 1, 0, 1, 0, 0, 0, R/-W. Bits 7 to 1 are the permanent address of the timekeeper on the bus. Bit 0, R/-W, specifies whether the present operation is a read operation, in which case R/-W is high, or a write operation, when R/-W is low.

After the slave address bits are transmitted, an eight-bit address byte is transmitted to the IC to specify a particular memory location. The address is written to the address pointer of the IC and the value ranges from 0 to 64.

Following the write operation, the eight bits of the data are transmitted to the *41T56*. In read mode, after writing the address to the address pointer, a start condition is generated again and is followed by sending the slave address bits with the R/-W bit set to 1. Then the data stored in the memory is sent out.

For more details of the chip, obtain the manufacturer's data sheets referred to in the separate panel.

More information

'Stand-alone data logger"' Pei An and Pinhua Xie, *Electronics World*, March 1998

PC Interfacing – Using Centronics, RS232 and game ports, Pei An, Newnes, Butterworth-Heinemann, 1998, ISBN0240514483

Data sheet for PIC16C84 microcontroller available from web site: http://www. microchip.com

Data sheet for MK41T56 time keeper and memory available from web site: http://www.st.com

Data sheet for 24LC65 64K EEPROM available from web site: http://www. microchip. com

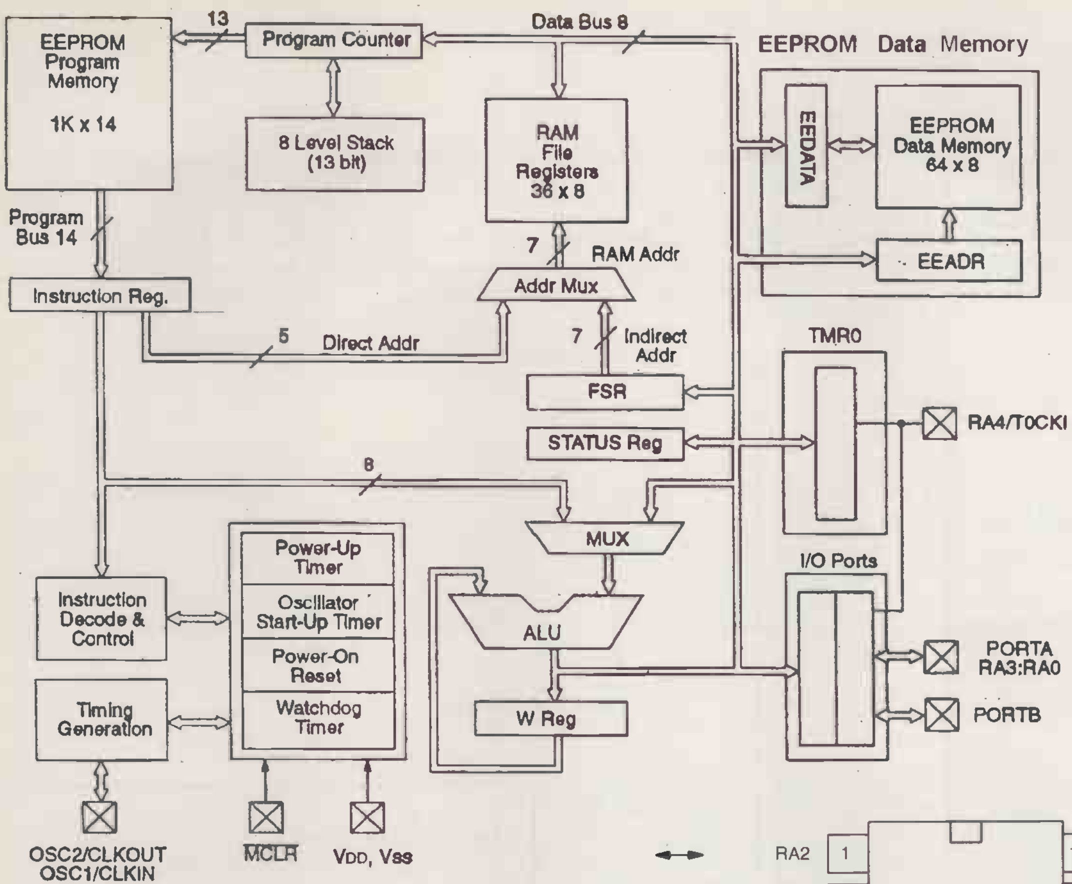
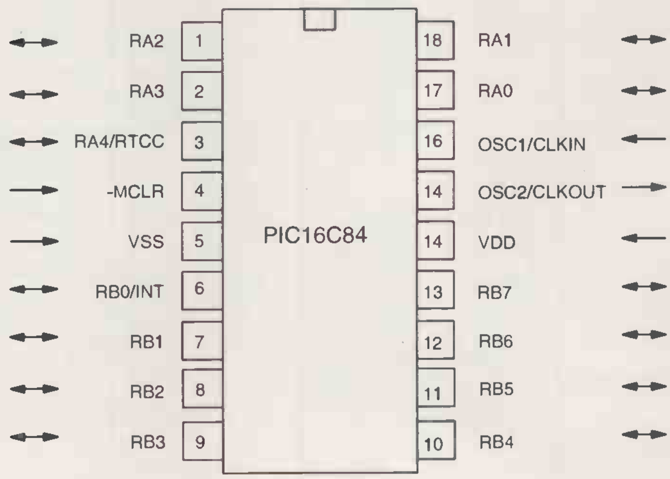


Fig. 4. Pin-out and internal block diagram of the PIC16C84 microcontroller. This is an 18-pin DIL device. There are only 35 instructions for programming the Pic.



In the present circuit, SCL and SDA are controlled by the Pic via RB3 and RB4 pins. Both lines are pulled to +5V by R_{11} and R_{12}, both 4.7kΩ, to form the I²C bus.

The Pic permanently sets the RB3 (SCL) line as an output line. The SDA line, RB4, is set as an input to the Pic or an output according I²C bus operations.

Memory unit

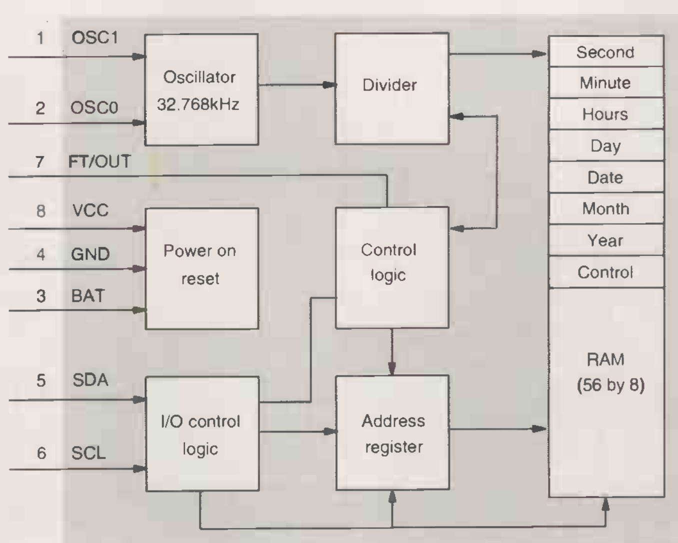
The memory unit is a 24LC65 8Kbyte 2.5V *SmartSerial* eeprom, which can be written to and erased up to 1 000 000 times. It requires a power supply 2.5V to 6V with a typical current consumption of 1mA in active mode and 1μA in standby mode.

Again, this device uses the I²C bus for data transfer and operates as a slave device. Pin-out and the internal block diagrams of the chip are given in **Fig. 7**.

Lines A0, A1 and A2 set the address of the chip. This allows up to eight chips to be used on the same bus, giving 64Kbyte total memory capacity. Lines designated SCL and SDA are the clock and data lines of the I²C bus. More details of the chip can be found in the fifth reference in the 'More information panel'.

Data can be written to and read from the ROM via the I²C bus. The write operation has two modes: byte-write mode and page-write mode. The former writes a single byte to a memory location. Page-write mode writes 64 bytes to a block in one go.

Read operations can be carried out in one of three modes –



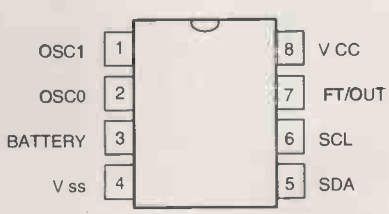


Fig. 5. Pin-out and internal block diagram of the MK41T56 timekeeper. It has an I²C bus, making hardware design easy.

Fig. 6. Timing sequence of the MK41T56 real-time clock.

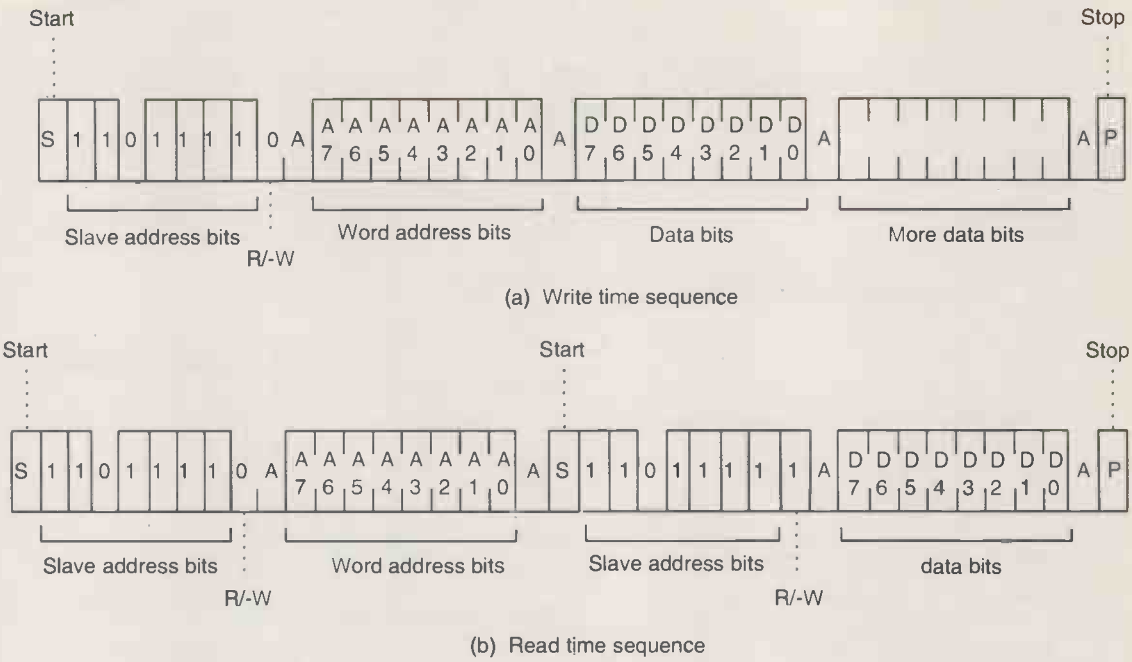
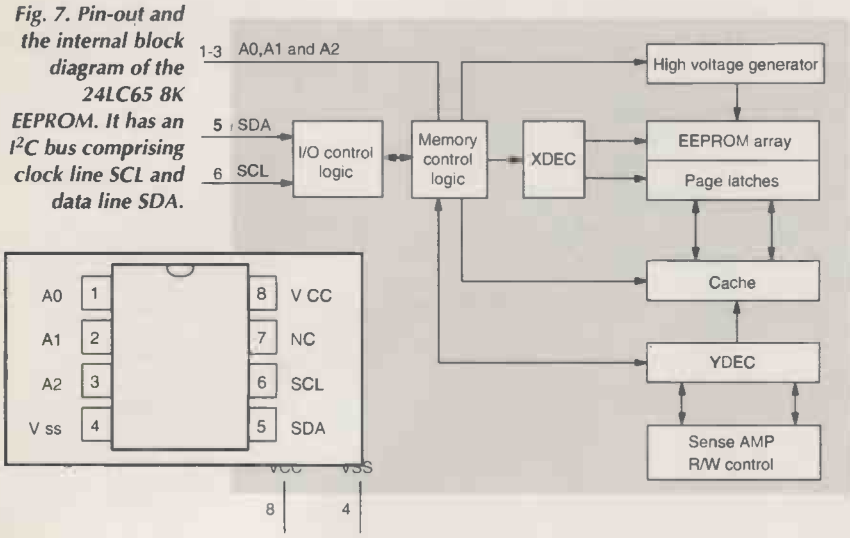


Fig. 7. Pin-out and the internal block diagram of the 24LC65 8K EEPROM. It has an I²C bus comprising clock line SCL and data line SDA.



Technical support

Kits comprising all components necessary – including pre-programmed Pic – to construct a complete stand-alone data logger are available from the authors. Source code for the Pic and the PC linker program are also available. Please make your enquiry to Dr Pei An at 11 Sandpiper Drive, Stockport, Manchester SK3 8UL, UK Tel/Fax/Answer: +44-(0)161-477-9583. E-mails should be addressed PAN@FS1.ENG.MAN.AC.UK.

Fig. 8. Timing sequence required for reading and writing the 24LC65 EEPROM.

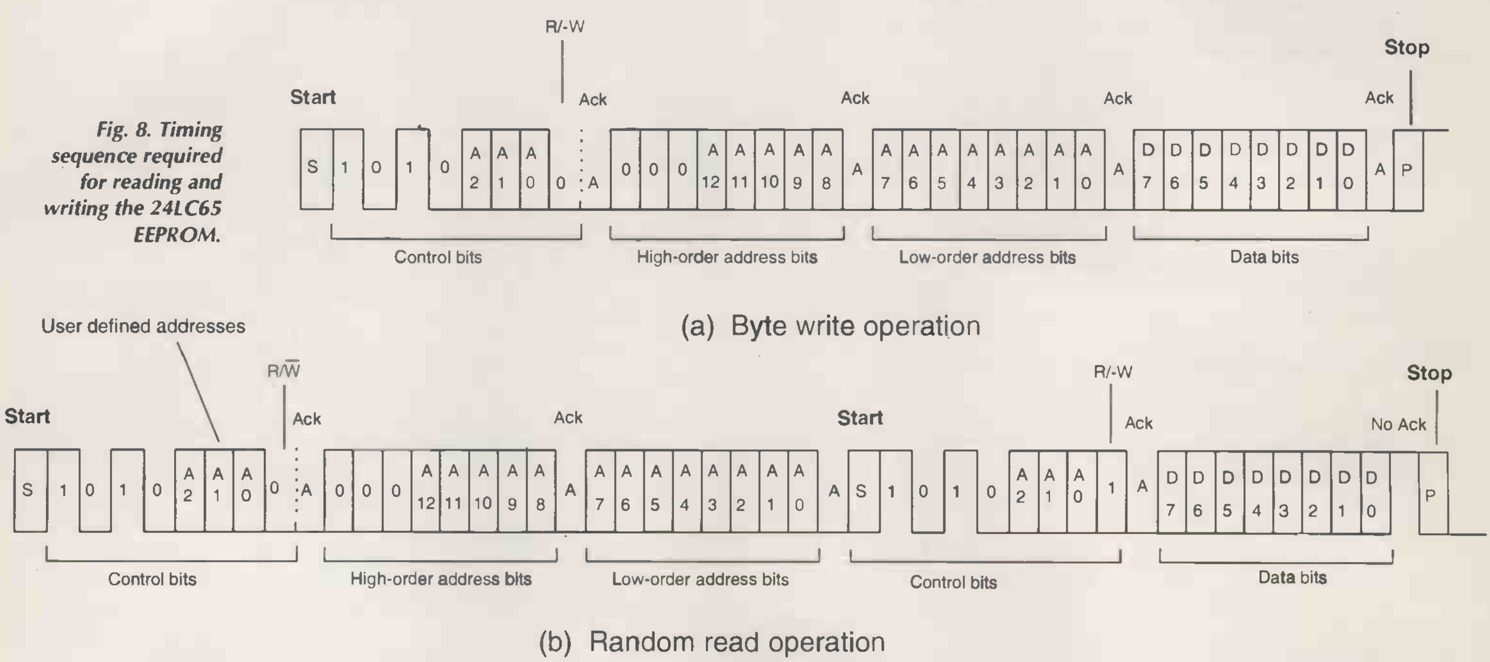
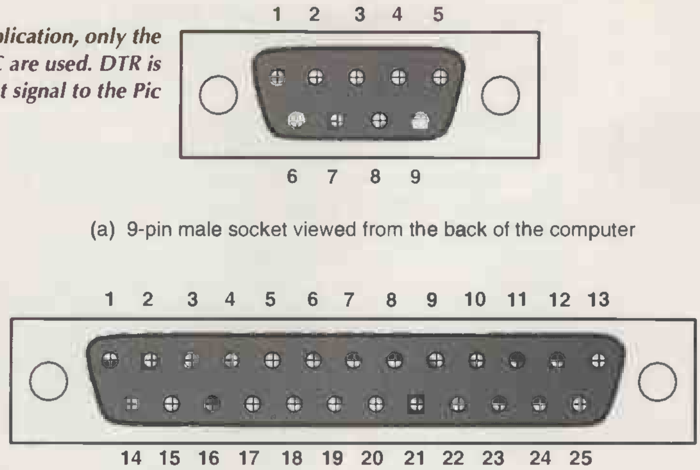


Fig. 9. Pin-out of the PC's RS232 COM port. In the present application, only the TX output from the PC, the RX input to the PC, and DTR from PC are used. DTR is used for generating the reset signal to the Pic



(a) 9-pin male socket viewed from the back of the computer

(b) 25-pin male socket viewed from the back of the computer

Pin functions of the RS232 connectors

25 pin	9 pin	Name	Direction (for PC)	Description
1	–	Prot	–	Protective ground
2	3	TD	OUTPUT	Transmit data
3	2	RD	INPUT	Receive data
4	7	RTS	OUTPUT	Request to send
5	8	CTS	INPUT	Clear to send
6	6	DSR	INPUT	Data set ready
7	5	GND	–	Signal ground (common)
8	1	DCD	INPUT	Data carrier detedt
20	4	DTR	OUTPUT	Data terminal ready
22	9	RI	INPUT	Ring indicator
23		DSRD	I/O	Data signal rate detector

current address read, random read and sequential read. The byte write modes and random read modes are used in this application. Their timing sequence is described below, **Fig. 8**.

The byte-write operation is as follows. Following a start condition on the I^2C bus, the control code, 1010_2, the device address on A2, A1 and A0, and the R/-W bit are placed onto the bus by the Pic. The R/-W bit should be zero to indicate a write operation. Address lines A2, A1 and A0 should be the same as the hardware setting on the memory chip.

The next byte transmitted by the Pic is the high-order byte of the address and will be written into the address pointer of the *24LC65*. The following byte is the least-significant address byte. After receiving another acknowledge signal from the *24LC65* the Pic transmits the data byte into the memory.

Random-read mode allows the Pic to access any memory locations in a random manner. Following a start condition on the I^2C bus, the control code, 1010_2, the device address, A2, A1 and A0, and the zero R/-W bit are placed onto the bus by the Pic.

The following byte transmitted by the Pic is the high-order byte of the word address and will be written into the address pointer of the *24LC65*. The next byte is the least significant address byte.

After receiving another acknowledge signal from the *24LC65* the Pic generates a start condition again and then it transmits the control byte to the memory. This time the R/-W bit is 1 to indicate a read operation. The *24LC65* acknowledges and outputs the addressed byte bit by bit. The Pic finally generates a stop condition.

In the present circuit, SCL and SDA are controlled by the Pic via RB3 and RB4 pins. Both lines are pulled to +5V by R_{11} and R_{12} to form the I^2C bus. The Pic permanently sets the SCL line on RB3 as an output. Data line SDA is set as an input to the Pic or an output according to I^2C bus operations.

RS232/TTL translator unit

Conversions between RS232 and TTL logic levels are performed by this section. From the circuit diagram, you can see that the RX line – the line from which the logger receives data at RS232 voltage level – is converted into a TTL voltage level using a simple voltage clamp circuit based on R_1 and a zener diode D_1.

The converter does not invert. The TX signal – the signal output from the logger at RS232 voltage level – is generated by a circuit comprising R_2, R_3 and T_1. The circuit requires positive and negative power supplies. The positive supply is from the +5V rail of the data logger board. The negative supply is derived from the RS232 port of the PC.

The transmit line, Tx, in the PC's RS232 port is always low, i.e. at –10V, while the PC is not outputting data. This arrangement can be used in the system because the event logger does not read and output data at the same time.

The DTR line in the PC's RS232 port is used to reset the event logger before initialisation and data downloading. The pin-out of the PC's RS232 port connector and its functions are given in **Fig. 9**. Detailed descriptions of the port and its software control can be found in the second reference in the separate panel.

Power supply unit

The circuit of the power supply unit is given in Fig. 3. The power supply is a PP3 9V battery regulated to +5V using an *HT1050* regulator. The 1050 is a 5V fixed regulator with a maximum supply current 30mA. It offers a very low dropout

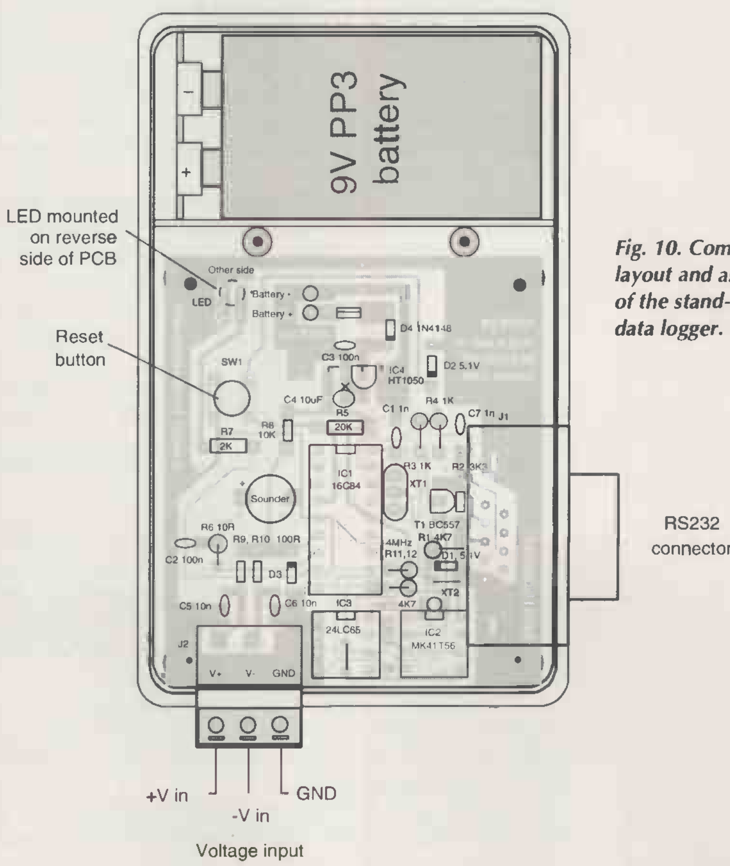


Fig. 10. Component layout and assembly of the stand-alone data logger.

voltage of 100mV and a quiescent current of 3.5μA.

The complete circuit consumes approximately 2mA during operation.

Implementation and applications

The stand-alone data logger may be constructed on a single-sided circuit board and is housed in a slim size ABS box. **Figure 10** gives the component layout and the assembly of the logger inside the box.

A dry-reed switch and a small magnet of the type used in home security systems can be used as the event sensor to log door openings. When the door is closed, the dry-reed switch is closed. The event trigger input is pulled to the logic-low state.

When the door is opened, the switch opens and the input line goes logic high, triggering the event logger. The dry-reed switch is a passive component. It does not required any external power supplies.

A vibration sensor – as used in home security systems – or a tilt sensor can be used for detecting movement. If there is no movement, the state of the sensor switch may be open or closed. When the sensor is moved, it will open and close, triggering the event logger. Again, these sensors are passive components and do not require external power supplies.

Software

The Pic's software enables it to communicate with a host PC during initialisation and downloading data, and to write time stamps to on-board memory if events are detected.

Software on the PC is needed to initialise the event logger and to download data from it. My Pic software is written in *16C84* assembly language and my PC software is in Turbo Pascal 6.

Pic software driver

The *16C84*'s command set contains 35 instructions, each a single 14-bit word.

I edited the software code in a Windows-based Pic development environment. The assembly code is converted into machine codes using the micro assembler MASM. The machine code is then programmed into a *16C84* using a Pic programmer. Next, the programmed Pic is plugged into the event logger for testing.

The Pic software has the following functions: (a) to communicate with a host PC during initialisation, (b) to communicate with the PC during data download and (c) to respond to an event in the data logging mode.

After reset – i.e. the reset button is pressed and released – once the logger receives a byte AA_{16} from the TX line of the PC's RS232 port, it enters initialisation mode. Then the logger receives 13 more bytes from the PC. The first six bytes are the event logging start time – minute, hour, day of week, day, month and year – and the next 7 bytes are the current time – second, minute, hour, day of week, day, month and year.

Transmitted and received serial data has the following format: bit rate=9600, no parity check, eight-bit word length and one stop bit.

After the Pic receives these bytes, it goes into sleep mode and waits for the start time to come.

The Pic uses an interrupt scheme to respond to an incoming event. The interrupt is generated at the RB0/INT pin. The Pic software sets the rising edge at the RB0/INT pin as the interrupt trigger. When the event sensor generates a low-to-high signal, the Pic wakes up from sleep, reads the current time from the clock and stores a five-byte time stamp into the EEPROM. Next, the Pic goes back to sleep and waits for the next event.

After reset, if the Pic receives 55_{16} from the PC, the event logger enters data download mode. It first sends the start time (six bytes) and two bytes indicating the total number of events recorded, most-significant byte first.

Next the Pic sends out all the time stamps. Each stamp consists of five bytes: second, minute, hour, day, month. Data are sent into the PC via the RX line of the RS232 port.

The complete Pic program is lengthy and it is not practical to list the complete source code in the article. However, the 'Technical support panel' explains how it can be obtained.

In this article, three sample subroutines are described for outputting a serial byte to a PC, inputting a serial byte from a PC and for communicating via the I^2C bus.

List 1 is a subroutine to send out a byte from RA0. The byte is contained in the DATA file register. **List 2** is a subroutine by which the Pic reads serial data from RA1. The RA1 pin must be configured as an input first. The received data is stored in the DATA file register.

Lists 3, 4 and **5** are I^2C bus drivers for sending data to and receiving data from a device. The basic operations of the I^2C bus are summarised as follows:

Start: RB4 (SDA) goes low while RB3 (SCL) is high.
Stop: RB4(SDA) goes high while RB3(SCL) is high.
Acknowledgement: Pic generates an acknowledgement-related clock after a byte is transferred on the bus. The acknowledge is a logic low at the SDA line of the bus during the acknowledgement clock. The acknowledgement is generated by the device receiving data.
Pic sends one byte to devices: A data bit is placed on RB4 (SDA) pin while RB3 (SCL) is low. Then RB3 (SCL) is pulled high. This is repeated eight times to transfer a byte.
Pic receives a byte: A data bit is read from RB4 (SDA) while RB3 (SCL) is high. This is repeated eight times to get a complete byte.

Writing data into a device involves the following activities on the I^2C bus: start; send a control word; send addresses; send data; stop. The source code is listed in List 3.

Reading data into the Pic involves the following activities on the bus: start; send a control word (R/-W bit = 0); send addresses; send the control word (R/-W bit=1); read data; stop. The source code for read data into the Pic is shown in List 4.

List 5 contains procedures to generate Start, Stop and acknowledgement-related clock.

PC software driver

The software examples shown here are written in Turbo Pascal 6. The software can be converted into other programming languages such as Visual Basic and Visual C++ languages.

The PC communicates with the event logger using the RS232 port. In Turbo Pascal, the command to output a byte from the PC's serial port is:

```
Port[RS232_address]= data_out
```

and the command to receive data from the serial port is:

```
data_in=Port[RS232_address].
```

RS232_address is the base address of the selected RS232 port. Data_out and Data_in are bytes.

List 6 is a useful procedure to find out the number of COM port installed on a PC and allows you to choose one.

List 7 is a procedure used to initialise the event logger. Procedur write_port (dummy_address, databyte:byte) writes the databyte into the selected RS232 port.

List 8 is a procedure for downloading data from the event logger. During download, the event logger sends out the serial data byte by byte continuously regardless of whether the PC receives data for not.

To catch every byte sent by the event logger, the PC must read data from the serial port automatically once a complete byte is received. The function 'data:byte' is a function to perform such a task. Before using this function, the selected RS232 port is configured to generate interrupt identification flag upon receipt of a byte. This is done by issuing Port[RS232_address+1]:=1 command. ■

Turbo Pascal 6 and Pic assembler listings for the stand-alone event logger.

List 1.

```
TOPC    BCF     PORTA,PA0   ;bit clear PA0, PA0 outputs 0
        CALL    D9600       ;call delay D9600, gives a
                            delay for 9600 baud rate
        MOVLW   8           ;move literal 8 into W
        MOVW    CUNTER      ;move into COUNTER - a general
                            purpose file reg. Counter
                            should be defined in program
                            header
START1  BTFSS   DATA,BIT0   ;test BIT 0 of DATA, skip if
                            1. Gen. purpose file register
        GOTO    TLO0        ;GOTO TLO0
        BSF     PORTA,PA0   ;bit set PA0, PA0 outputs 1
        GOTO    THL0        ;goto THLO
TLO0    BCF     PORTA,PA0   ;bit clear PA0, PA0 outputs 0
THL0    CALL    D9600       ;call a delay for the present
                            bit
        RRF     DATA        ;DATA is bit rotated right.
                            Previous BIT1 becomes BIT0
        DECFSZ  COUNTER     ;COUNTER-1, skip next code if
                            COUNTER=0, repeat 8 times
        GOTO    START1      ;goto START1
        BCF     PORTA,PA0   ;bit clear PA0, PA0 outputs 0.
                            This bit is the stop bit
CALL    D9600               ;call a delay
        BSF     PORTA,PA0   ;bit set PA0, PA0 output 1
        CALL    D9600       ;call more delays
RETURN
```

List 2

```
FRPC    CLRWDT              ;clear watchdog timer
        BTFSC   PORTA,PA1   ;bit test of PA1, skip if 0.
                            Data transmission on RS232
                            port begins with a low-going
                            start bit
        GOTO    FRPC        ;goto FRPC
        CALL    FD9600      ;call FD9600 delay procedure
                            to delay a half bit period
        CALL    D9600       ;call D9600 delay procedure to
                            delay a bit period this ensure
                            that the next reading is at
                            the middle of the 1st bit
                            which is the MSB.
MOVLW   8                   ;move literal 8 into W
        MOVW    CUNTER      ;move 8 into COUNTER which is
                            defined in the program header
        BTFSS   PORTA,PA1   ;bit test of PA1, skip if it
                            is 1
        GOTO    PLO0        ;jump to PL00
        BSF     DATA,BIT7   ;bit set BIT7 of the DATA
                            register, BIT7=1
        GOTO    PHL0        ;jump to PHLO
PLO0    BCF     DATA,BIT7   ;bit clear BIT7 of the DATA
                            register, BIT7=0
PHL0    CALL    D9600       ;call a bit period delay.
RRF     DATA    ;DATA is bit rotated right. Previous BIT7
                            becomes BIT6
        DECFSZ  COUNTER     ;COUNTER-1, skip if COUNTER=0,
                            repeat 8 times
        GOTO    START1      ;GOTO START1
RETURN
```

List 3

```
WRITE   CALL    STRAM       :generate a START
        MOVF    CWORD,W     ;load control word CWORD into
                            W
        MOVWF   TRAM        ;load CWORD into TRAM register
        CALL    TORAM       ;send out CWORD bit by bit on
                            the bus. TORAM is a procedure
                            to clock out data bit by bit
        BCF     PORTB,PB4   ;PB4 is pulled low
        CALL    ACKCLK      ;generate an ack clock
        MOVF    ADDR,W      ;load address byte into W
        MOVWF   TRAM        ;as above
        CALL    TORAM
        BCF     PORTB,PB4
        CALL    ACKCLK
        MOVF    DATA,W      ;load data byte into W
        MOVWF   TRAM        ;as above
        CALL    TORAM
        BCF     PORTB,PB4
        CALL    ACKCLK
        CALL    STOP        ;generate a stop
        CALL    MDELAY
RETURN
```

List 4

```
READ    CALL    STRAM       ;generate a start condition
        MOVF    CWORD,W     ;load control word (CWORD)
                            into W
        MOVWF   TRAM        ;load W into TRAM register
        CALL    TORAM       ;send CWORD bit by bit on bus.
        BCF     PORTB,PB4
        CALL    ACKCLK
        MOVF    ADDR,W      ;send out address to the
                            device
        MOVWF   TRAM
        CALL    TORAM
        BCF     PORTB,PB4
        CALL    ACKCLK
        CALL    STRAM       ;generate a start condition
                            again
        BSF     CWORD,BIT0  ;enable R/-W bit of control
                            word
        MOVF    CWORD,W     ;load control word to W
        MOVWF   TRAM
        CALL    TORAM       ;send out CWORD
        BCF     CWORD,BIT0
        BCF     PORTB,PB4
        CALL    ACKCLK
        CALL    FRRAM       ;read 8 bits of data from the
                            bus. FRRAM is a procedure to
                            to read an 8-bit data into Pic
                            bit by bit
        BSF     PORTB,PB4
        CALL    ACKCLK      ;generate an ACK clock
        CALL    STOP        ;Call a stop condition
        RETURN
```

List 5

```
STRAM   BSF     PORTB,PB4   ;generate a start condition
BSF     PORTB,PB3
        CALL    SDELAY
        BCF     PORTB,PB4
        CALL    SDELAY
        BCF     PORTB,PB3
        CALL    SDELAY
        RETURN
;***********************************************
STOP    BCF     PORTB,PB4   ;generate a stop condition
        CALL    SDELAY
        BSF     PORTB,PB3
        CALL    SDELAY
        BSF     PORTB,PB4
        CALL    SDELAY
        RETURN
;***********************************************
ACKCLK  BSF     PORTB,PB3   ;generate acknowledge clock
        CALL    SDELAY
        BCF     PORTB,PB3
        CALL    SDELAY
        RETURN
```

List 6

```
Procedure detect_RS232;
{Universal auto detection of COM base address. User section
                            of RS232 port}
{ $0000:$0400 holds the printer base address for COM1
  $0000:$0402 holds the printer base address for COM2
  $0000:$0404 holds the printer base address for COM3
  $0000:$0406 holds the printer base address for COM4
  $0000:$0411 number of parallel interfaces in binary
                            format}
var
   COM:array[1..4] of integer;
   kbchar:char;
begin
      clrscr;
      COM_number:=1; {default printer}
      number_of_COM:=mem[$0000:$0411]; {read number of
                            parallel ports}
      number_of_COM:=(number_of_COM and (8+4+2)) shr 1;
      COM[1]:=memw[$0000:$0400];       {Memory read
                            procedure}
      COM[2]:=memw[$0000:$0402];
      COM[3]:=memw[$0000:$0404];
      COM[4]:=memw[$0000:$0406];
      textbackground(blue); clrscr;
      textcolor(yellow); textbackground(red);
                            window(10,22,70,24); clrscr;
      writeln('Number of COM installed    :
                            ',number_of_COM:2);
      writeln('Addresses for COM1 to COM4:  ',COM[1]:3,'
```

```
                         ', COM[2]:3,'   ', COM[3]:3,'
                         ', COM[4]:3);
     write('Select COM to be used (1,2,3,4)    :  ');
     delay(1000);
     if number_of_COM>1 then begin   {select COM1 through
                         COM4 if more than 1 LPT
                         installed}
       repeat
         kbchar:=readkey;                {read input
                         key}
         val(kbchar, COM_number, code);   {change
                         character to value}
       until (COM_number>=1) and (COM_number<=4) and
                         (COM[COM_number]<>0);
                          end;
     clrscr;
     RS232_address:=COM[COM_number];
     writeln('Your selected RS232 interface:
                         COM',COM_number:1);
     write('RS232  Address                    :
                         ',RS232_address:4);
     delay(5000);
     textbackground(black); window(1,1,80,25); clrscr;
end;
```

List 7

```
Procedure init_logger;
{initialize stand-alone data logger}
var
   dummy,i:integer;
begin
     textbackground(black);
     clrscr;
     writeln('Initialization of the data logger');
     sound(800);
     textcolor(red+blink);
     writeln('Press reset on the logger now');
     writeln('Then press RETURN');
     readln;
     nosound;
     textcolor(yellow);
     writeln;
     dummy:=input;
     clrscr;
     writeln('Initialization of the data logger');
     textcolor(yellow);
     writeln;
     getdate(year,month,day,dayofweek);
     gettime(hour,minute,second,second100);
     writeln('Present date: ',day,'/',month,'/',year);
     writeln('Present time: ',hour,':',minute,':',second);
     writeln;
     writeln('Input data logging launch time: ');
     write('Year  [00-99] = ');  readln(start_year);
     write('Month [1 -12] = ');  readln(start_month);
     write('day   [1 -31] = ');  readln(start_day);
     write('hour  [1 -24] = ');  readln(start_hour);
     write('minute[1 -60] = ');  readln(start_minute);
     reset; {rese the event logger}
     delay(5000);
     writeln('Initialization of the logger in
                         progress...');
     write_port(0,10*16+10); {send AA=10*16+10 byte};
     delay(5000);
     getdate(year,month,day,dayofweek); {read current PC
                         date}
     gettime(hour,minute,second,second100); {read current
                         PC time}
     {input launch time}
     write_port(0,BCD(start_minute)); {minute}
     delay(4000);
     write_port(0,BCD(start_hour)); {hour}
     delay(4000);
     write_port(0,BCD(start_day)); {day}
     delay(4000);
     write_port(0,BCD(start_day));
     delay(4000);
     write_port(0,BCD(start_month));
     delay(4000);
     write_port(0,BCD(start_year));
     delay(10000);
     {input current time}
     write_port(0,BCD(second));
     delay(3000);
     write_port(0,BCD(minute));
     delay(3000);
     write_port(0,BCD(hour));
     delay(3000);
     write_port(0,BCD(dayofweek));
     delay(3000);
     write_port(0,BCD(day));
     delay(3000);
     write_port(0,BCD(month));
     delay(3000);
     write_port(0,BCD(year-1900));
     writeln('Configuration completed');
     writeln('Press RETURN to continue');
     for i:=1 to 10 do dummy:=input;
     readln;
end;
```

List 8

```
Function data:byte;
{to read data from COM port with valid-data-received
                         detection}
var
   d1x,d2x:array [1..1005] of byte;
   datax:byte;
begin
     repeat until
                         (Read_interrupt_identification
                         (RS232_address) and 1) =0;
     {check if a valid serial data is received by the COM
                         port}
     data:=input;  {read the received data}
end;

Procedure readdata;
var
   i,dummy, d1, d2 :integer;
   Start_time :array [1..7] of byte;
   stamp: array [1..1000,1..7] of byte;
begin
     clrscr;
     reset; {reset the event logger}
     writeln('Data downloading...');
     getdate(year,month,day,dayofweek);
     gettime(hour,minute,second,second100);
     write('Present time: ',hour,':',minute,':',second,'
                         ');
     writeln('Present date: ',day,'/',month,'/',year);
     write('Input the file name to store data (path + name
                         + extension): ');
                         readln(filename);
     write_port(0,5*16+5); {send 55=5*16+5 byte};
     delay(5000);
     dummy:=data;
     for i:=1 to 6 do
       begin
         Start_time[i]:=bin(data);
         write(start_time[i]:3,'  ');
       end;
     writeln;
     ax:=data; bx:=data;
     total_number:=ax*256 + bx;
     ax:=data; bx:=data;
     address_pointer:=ax*256 + bx;
     writeln('Number of events recorded: ' ,total_number);
     for i:=1 to total_number do
     begin
         write(' ',i:3,'-');
         for ix:=1 to 7 do
         begin
           stamp[i,ix]:=bin(data);
           write(stamp[i,ix]:2,' ');
         end;
         if ((i) mod 3)=0 then writeln;
     end;
     {Save data into a file}
     assign(datafile,filename);
     rewrite(datafile);
     write(datafile,'Start time: minute, hour, day, month,
                         year : ');
     for i:=1 to 6 do write(datafile,Start_time[i],'  ');
     writeln(datafile);
     writeln(datafile,'Total number of events recorded:
                         ',Total_number:3);
     writeln(datafile,'Time stamps for events (event
                         number, second, minute, hour,
                         day, dayofweek, month, year)
                         ');
     for i:=1 to total_number do
       begin
           write(datafile,i:3,'  ');
           for ix:=1 to 7 do write(datafile,
                         stamp[i,ix]:2,' ');
           writeln(datafile);
       end;
     close (datafile);
     readln;
end;
```

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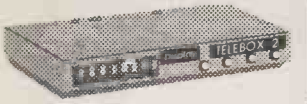

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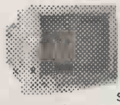

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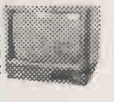

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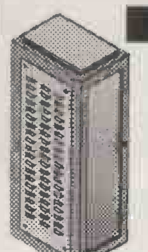

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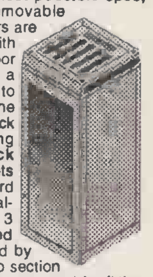

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CIRCUIT IDEAS

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Your submissions are judged mainly on their originality and usefulness. Interesting modifications to existing circuits are strong contenders too – provided that you clearly acknowledge the circuit you have modified. Never send us anything that you believe has been published before though.

Don't forget to say why you think your idea is worthy.

Clear hand-written notes on paper are a minimum requirement: disks with separate drawing and text files in a popular form are best – but please label the disk clearly.

Automatic load switch and timer

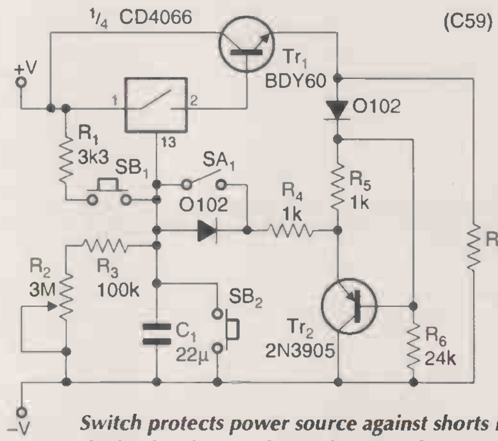
In addition to short-circuit protection, this circuit breaker switches off in a period between 1 and 30+ seconds to prevent battery discharge.

When the push-button SB_1 is pressed, C_1 charges from the power rail through R_1, the *4066* switches on and the power transistor Tr_1 is enabled. Switch SA_1 being normally open, C_1 discharges through R_2 and R_3, opening the 4066 switch to close down the series transistor and disconnect the load. If SA_2 is closed, the capacitor is held up by current through the diode, R_4 and R_5, as is the control pin of the *4066* to bypass the timing action.

For protection against load short-circuits, Tr_2 is included. This receives bias by way of R_5 and R_6 and discharges the capacitor to turn the circuit off in the normal way; resistor R_4 is a current limiter. Switch SB_2 switches the circuit off.

An input of 5-15V powers the arrangement and when not in operation the circuit draws very little current.

Michael A Shustov
Polytechnic University
Tomsk
Russia
C59



Switch protects power source against shorts in the load and times the application of power to a load.

Overvoltage load protection

Here is a circuit arrangement that senses excess voltage on a supply and isolates, and therefore protects, the load. In the case considered, the supply is 5V nominal for LS ttl, with a maximum allowable voltage of 5.25V.

The sensor is an *MC3423* overvoltage sensor which is programmable for other voltages by means of $R_{1,2}$; this one is set to 5.2V. If voltage at pin 2is over 5.2V, the output at pin 8 goes high to within 2.2V of V_{cc}, supplying a current of up to 100mA.

Normally, there is less than 5.2V on the load, the output of the 3423 is low and Tr_1 is off. Output of the *MAX233* RS232 receiver/driver, used here as a mosfet driver, is at 9V, its input at pin 2 being low; the diode is forward-biased and Tr_2 fully on to connect the load to the supply.

If the voltage across the load exceeds 5.2V, the reverse state of affairs applies and Tr_2 turns off to isolate the load. The 1µF capacitor imposes a 12ms time delay to avoid trouble caused by noisy supply lines. The diode is needed to protect the mosfet gate when the *MAX233* output goes to –9V.

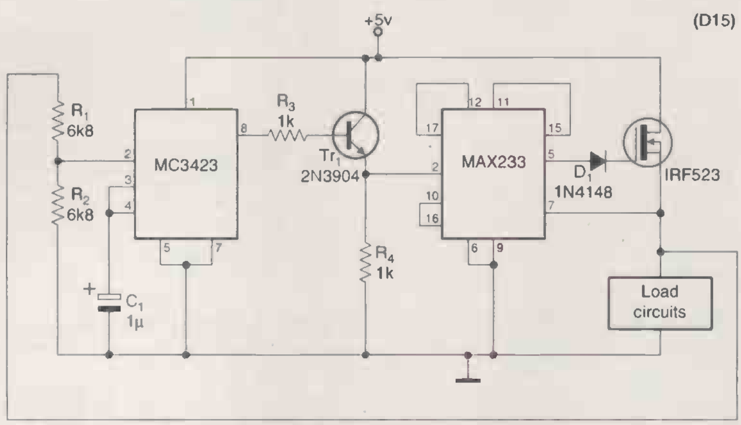
The value of R_2 should, for best drift performance, be less than 10kΩ and the internal reference V_{ref} of the 3243 is 2.6V. The equation for the selection of $R_{1,2}$ is,

$$V_{trip}=V_{ref}(1+(R_1/R_2))$$

and the time delay,

$$t_d=(12\leftrightarrow 10^3 C)\text{ seconds.}$$

Use of an overvoltage sensor and an RS232 driver and receiver, used as a mosfet driver, to isolate a load in the event of an excess of voltage from the supply.



V Lakshminarayanan
Bangalore
India D15

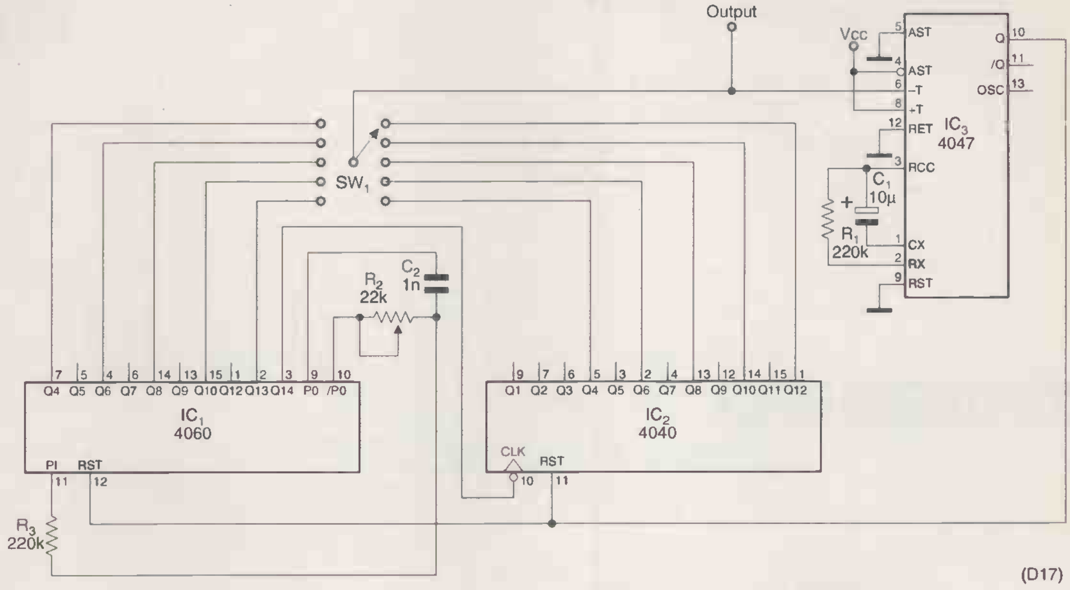
Variable pulse-width generator

What was needed here was a generator to provide a linearly variable pulse width from 500μs to 100s, a time between pulses of 3-5s, a pulse output of 8-15V and battery operation. Stability was unimportant, since a timer/counter with a precision clock was to be used to measure pulse width.

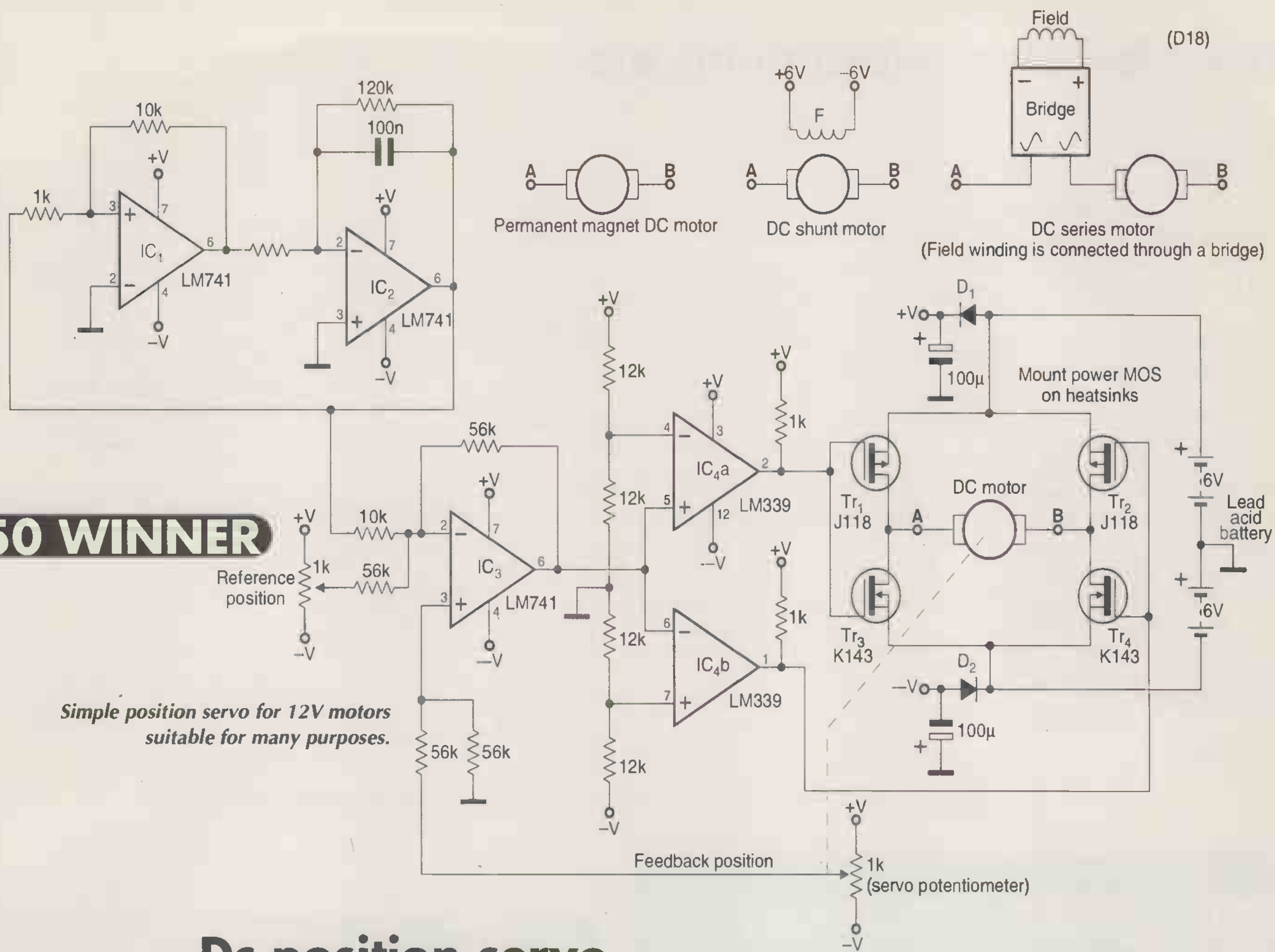
Timing for the *4060*'s oscillator is the function of R_2C_2, its output being divided by up to 214 times in the 4060 and 212 times in the *4040*, all outputs going to the selector switch. Pulse width selection is therefore by the switch and the variable resistor.

The *4047* is a one-shot, whose function is to determine the time between pulses, the falling edge of the selected waveform triggering the one-shot for a duration of 2.48*RC*, during which time the counters are reset. The selected output may only go high once before being reset by the 4047.

Jayant Kathe
Bombay
India



Pulse-width generator with minute control of pulse width from 500μs to 100s.



£50 WINNER

Simple position servo for 12V motors suitable for many purposes.

Dc position servo

This quite simple dc position servo may be used to drive a small 12V, permanent-magnet, series or shunt dc motor, the connections for all three being shown.

Matched pairs of mos transistors from a full bridge output stage, with diode isolation to avoid the effect of current drawn by this stage affecting the drive stage. A triangular wave from the generator formed by $IC_{1,2}$ is added to the error voltage, derived from the servo potentiometer, in the error amplifier IC_3, this also acting as a proportional controller with unity gain (changing the values of the 56kΩ resistors varies the gain). Window comparator IC_4 switches the bridge transistors on and off depending on whether the error voltage is positive or negative.

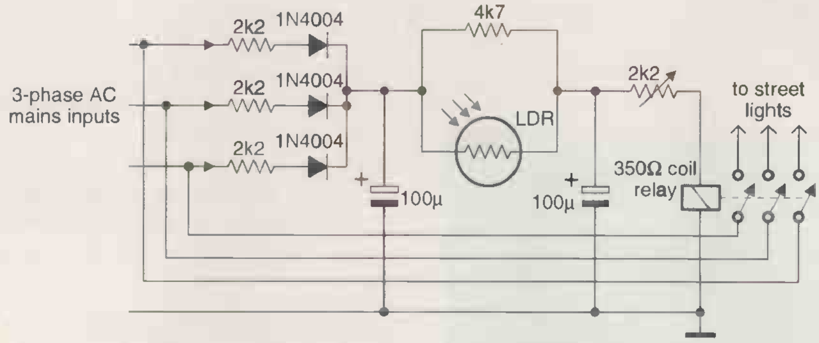
M T Iqbal
Rawalpindi
Pakistan
D18

Street-light controller

Normally, three-phase street lighting controllers will throw a street into total darkness if one phase fails; this one leaves lights on the other two phases operational. It also does not burn out relay coils quite so regularly.

Power to the relay comes from an Ored combination of inputs from the three phases via current limiting resistors and smoothing capacitors, rated at 300V. A light-dependent resistor with a voltage limiting resistor across it then turns the normally-closed relay on and off at the relevant ambient light levels, adjustable by the 2.2kΩ variable resistor. Resistors should be 5W wire-wound types.

Sode-shinni N J Rumala
Ahmada Bello University
Zaria
Nigeria, D19



Check that the 1N4004's PIV is sufficient for your local mains supply – Ed.

Relay coils show a tendency to last longer in this street-light controller, which does not cast whole neighbourhoods into darkness when one phase fails.

Phase-linear crossover

Cahner asked why his crossover filter is not perfect in the April issue letters pages. The answer is that, while it provides a good result in the frequency domain, there is a 90° phase shift between high and low frequency responses. Near the crossover region, this shift makes the sound radiation pattern frequency-dependent. It also produces nodes and troughs in the resulting waveform when the two are added together again at the ear.

One way of obtaining a virtually flat group delay is to make a circuit having a linear phase response. Two types of active filter are suitable: the Bessel and the all-pass or Deliyannis filter. (A high-pass filter cannot be used with them, since it produces a phase lead, while the two mentioned cause a phase lag.) The Bessel has several advantages over other types such as the Butterworth or Tchebychev: it has the most linear phase response, is highly damped, minimal distortion in the time domain, good pulse response and little ringing.

In **Fig. 1**, A_4 and A_5 form a fourth-order, two-stage Bessel filter whose gain may be precisely set to near the ideal value for the Bessel. Equal-value *R*s and *C*s may also be used in the frequency determining networks, the resistors being *MRS25* series metal-film types from RS Components.

Section A_2 is the all-pass, constant time-delay Deliyannis filter, its second-order all-pass form having the same effect on phase response as the fourth-order Bessel. For a second-order needs a gain of 0.25 and the ratio R_{22}:R_{21} must be 0.75 for a Deliyannis.

Section A_1 is an isolator from the low-pass filter, gives an equivalent gain to the low-pass Bessel and additional gain to offset the 0.25 loss in the all-pass filter. Section A_3 is a differential amplifier that subtracts the phase-shifted low-pass output from the all-pass phase-shifted one to give the high-pass signal. All-pass and low-pass signals are now more nearly in step, so that the differential amplifier has an easier job.

The test point allows the viewing of combined frequency and phase responses by means of a simulator such as Proteus or other cad programs. Doing this shows a remnant of phase shift between outputs, albeit much reduced.

Different frequencies may be obtained by changing the values of all the capacitors using the *fRC* equations, 1% polypropylene or polystyrene types being best.

Note that f_0, the design frequency, is not the crossover frequency, since Bessel filters are in use, which need a normalising factor. This circuit was for an electrostatic hf unit and an isobaric lf type.

Peter Latsky
Fordingbridge
Hampshire
D14

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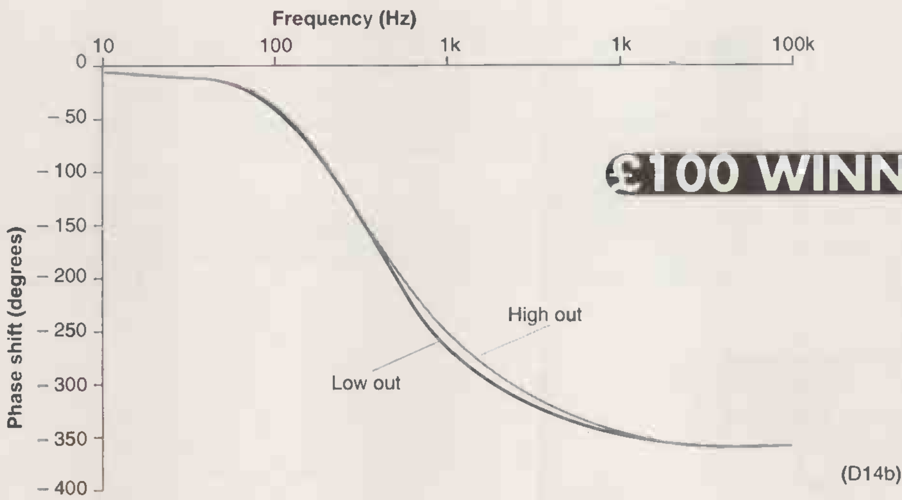

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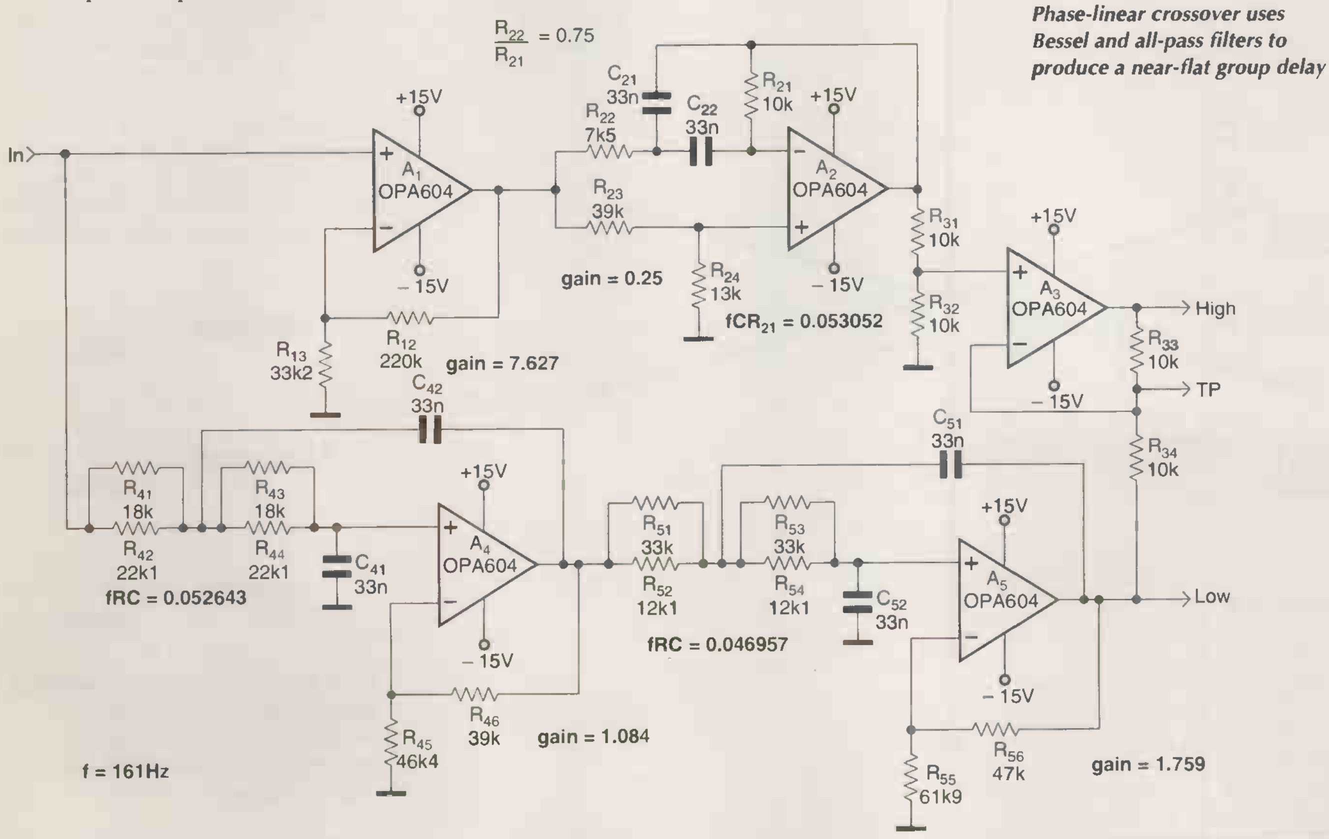


Crystals made clear I

Joe Carr explains how quartz crystals work, and how to get the best from them in a variety of oscillator circuits.

Radio-frequency oscillators can be built using a number of different types of frequency selective resonator. Common types include inductor-capacitor, i.e. *LC*, networks and quartz crystal resonators. The crystal resonator has, by far, the best accuracy and stability.

Piezoelectric crystals

Certain naturally-occurring and man-made materials exhibit the property of piezoelectricity: Rochelle salts, quartz and tourmaline are examples.

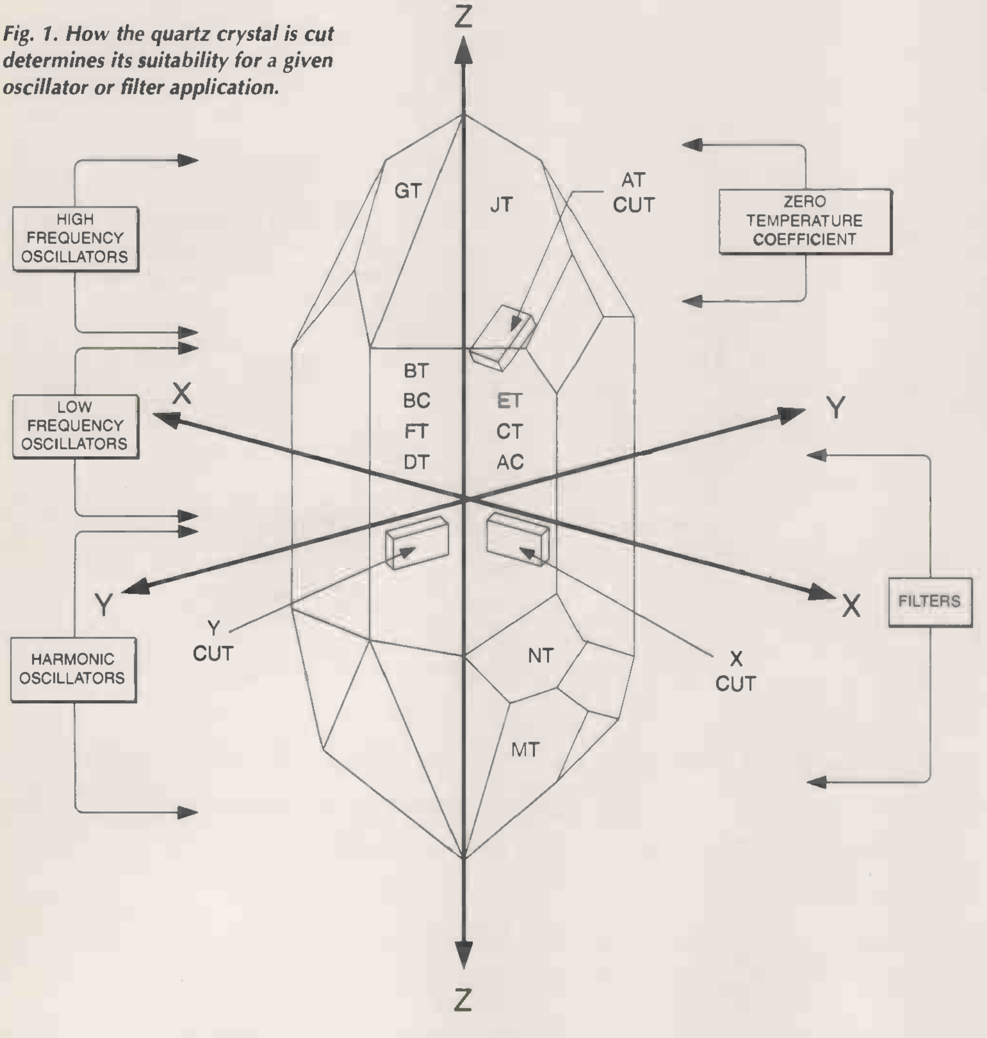
Rochelle salts crystals are not used for RF oscillators, although at one time they were used extensively for phonograph pick-up cartridges. Tourmaline crystals can be used for some RF applications, but are not often used due to high cost.

Tourmaline is considered a semiprecious stone, so tourmaline crystals are more likely to wind up as gemstones in jewelry than radio circuits. That leaves quartz as the preferred material for radio crystals.

Figure 1 shows a typical natural quartz crystal. Actual crystals rarely have all of the planes and facets shown. There are three optical axes – X, Y and Z – in the crystal used to establish the geometry and locations of various cuts.

The actual crystal segments used in RF circuits are sliced out of the main crystal. Some slices are taken along the optical axes, so are called Y-cut, X-cut and Z-cut slabs. Others are taken from various sections, and are given letter designations such as BT, BC, FT, AT and so forth.

Fig. 1. How the quartz crystal is cut determines its suitability for a given oscillator or filter application.



Piezoelectricity

All materials contain electrons and protons, but in most materials their alignment is random. This produces a net electrical potential in any one direction of zero. But

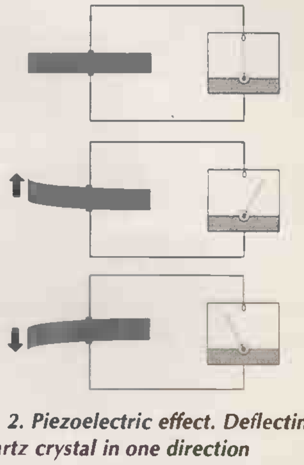


Fig. 2. Piezoelectric effect. Deflecting a quartz crystal in one direction produces a positive potential, deflecting it in the other produces a negative potential.

in crystalline materials the atoms are lined up, so can form electrical potentials. Piezoelectricity refers to the generation of electrical potentials due to mechanical deformation of the crystal.

Figure 2 shows the piezoelectric effect. A zero-center voltmeter is connected across a crystal slab. In the top circuit, the slab is at rest, so the potential across the surfaces is zero. But in the next circuit down, the crystal slab is deformed in the upward direction, and a positive potential is seen across the slab. When the crystal slab is deformed in the opposite direction, a negative voltage is noted.

If the crystal is mechanically 'pinged' once it will vibrate back and forth, producing an oscillating potential across its terminals, at its resonant frequency. Due to losses though the oscillation dies out in short order. But if the crystal is repetitively pinged, then it will generate a sustained oscillation on its resonant frequency.

It is not terribly practical though to stand there with a tiny hammer pinging the crystal all the while you want the the oscillator to run.

Fortunately though, piezoelectricity also works in the reverse mode: if an electrical potential is applied across the slab it will deform. Thus, if you amplify the output of the crystal, and then feed back some of the amplified output to electrically 're-ping' the crystal, then it will sustain oscillation on its resonant frequency.

Equivalent circuit

Figure 3a) shows the equivalent *RLC* circuit of a crystal resonator, while Fig. **3b)** shows the impedance versus frequency plot for the crystal.

There are four basic components of the equivalent circuit: series inductance, L_S, series Resistance, R_S, series capacitance, C_S, and parallel capacitance, C_P. Because there are two capacitances, there are two resonances: series and parallel. The series resonance point is where the impedance curve crosses the zero line, while parallel resonance occurs a bit higher on the curve.

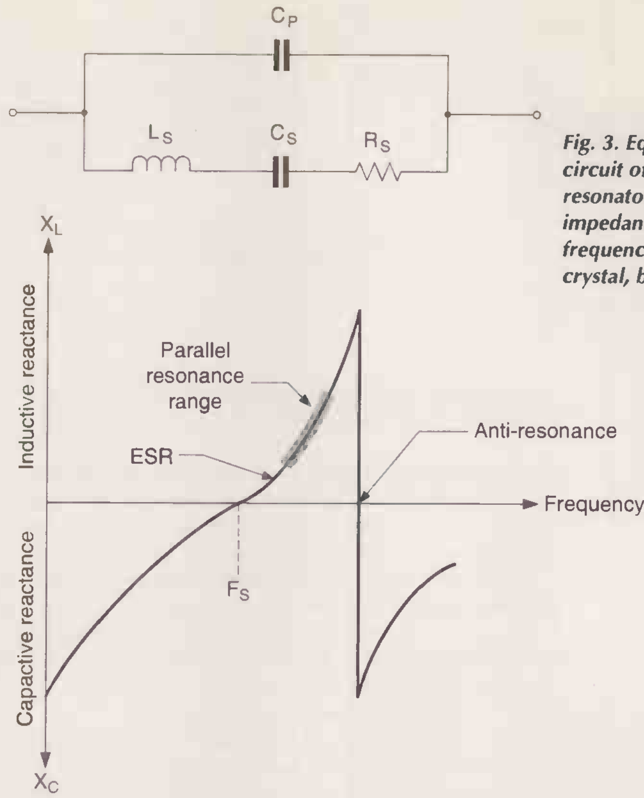


Fig. 3. Equivalent RLC circuit of a crystal resonator, a), and impedance versus frequency plot for the crystal, b).

Crystal packaging

Over the years a number of different packages have been used for crystals. Even today there are different styles. **Figure 4a)** shows a representation of the largest class of packages. It is a hermetically sealed small metal package, in various sizes. The actual quartz crystal slab is mounted on support struts inside the package, Fig. **4b)**, which are in turn mounted to either a wire header or pins.

Some crystals use pins for the electrical connections, and are typically mounted in sockets. The pin type of package can be soldered directly to a printed circuit board, but care must be taken to keep from fracturing the crystal with heat. Not all pins are easily soldered, although it can help if the pins are scraped to reveal fresh metal before soldering. Normally, however, if the crystal is soldered into the circuit a wire-lead package is used.

Some crystals may short circuit if installed on a printed circuit board with either through via holes or a ground plane on the top side of the board. In those cases, the usual practice is to insert a thin insulator between the PCB and the crystal, **Fig. 4c)**.

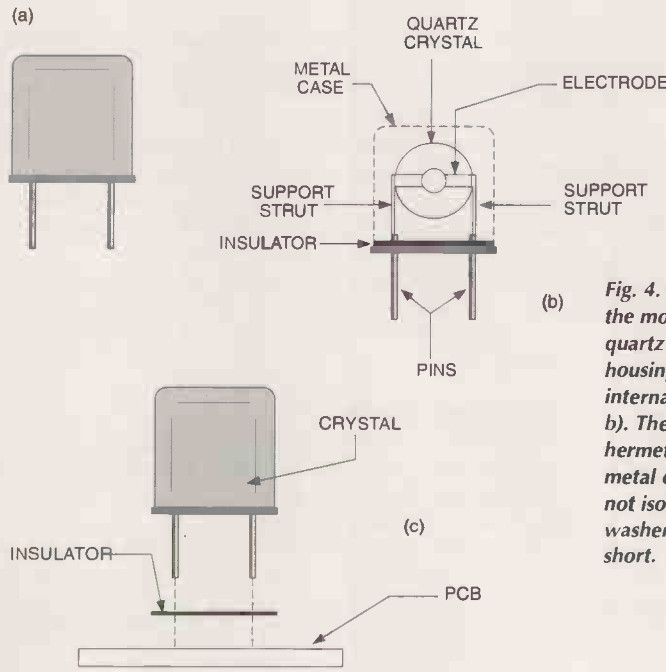


Fig. 4. Structure of the most common quartz crystal housing, a) and internal connections, b). The housing is an hermetically-sealed metal can which, if not isolated by a washer, may cause a short.

Temperature performance

There are three basic categories of crystal oscillator: room temperature crystal oscillators, or RTXOs, temperature compensated crystal oscillators, or TCXOs, and oven controlled crystal oscillators, OCXOs. Let's take a look at each of these groups.

Room-temperature crystal oscillators. The RTXO takes no special precautions about frequency drift. But with proper selection of crystal cut, and reasonable attention to construction, stability on the order of 2.5 parts per million, i.e. 2.5×10^{-6}, over the temperature range 0°C to 50°C is possible. The RTXO is only used on economy model counters used for non-critical applications.

Temperature-compensated crystal oscillators. The TCXO circuit also works over the 0°C to 50°C temperature range, but is designed for much better stability. The temperature coefficients of certain components of the TCXO are designed to counter the drift of the crystal, so the overall stability is improved to 0.5 PPM (5×10^{-7}). The cost of TCXOs has decreased markedly over the years to the point

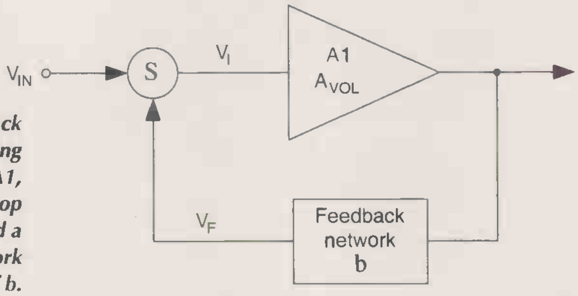


Fig. 5. Feedback oscillator comprising an amplifier, A1, with an open-loop gain of A_{vol} and a feedback network with a gain of b.

where relatively low cost upgrades to economy counters gives them a rather respectable stability specification.

Oven-controlled crystal oscillators. The best stability is achieved from the OCXO time base. These oscillators place the resonating crystal inside a heated oven that keeps its operating temperature constant, usually near 70°C or 80°C.

There are two forms of crystal oven used in OCXO designs, namely on/off and proportional control. The on/off type is similar to the simple furnace control in houses. It has a snap action that turns the oven heater on when the internal chamber temperature drops below a certain point, and off when it rises to a certain maximum point.

The proportional control type operates the heating circuit continuously, and supplies an amount of heating that is proportional to the actual temperature difference between the chamber and the set point. The on/off form of oven is capable of 0.1 ppm (10^{-7}).

Oven-controlled crystal oscillators that use a proportional control oven can reach a stability of 0.0002 ppm (2×10^{-10}) with a 20-minute warm-up and 0.0001 ppm (1.4×10^{-10}) after 24 hours.

It is common practice to design the counter to leave the OCTX turned on even when the counter is off. Some portable frequency counters, such as those used in two-way radio servicing, have a battery back-up to keep the OCXO turned on while the counter is in transit.

The variation described above is referred to as the temperature stability of the counter time base. We must also consider short-term stability and long-term stability, i.e. ageing.

Short-term stability

The short-term stability is the random frequency and phase variation due to noise that occurs in any oscillator circuit. It is sometimes also called either time domain stability or fractional frequency deviation.

In practice, the short-term stability has to be a type of RMS value averaged over one second. The short-term stability measure is given as $\sigma(\Delta f/f)(t)$. Typical values of short-term stability are given below for the different forms of clock oscillator.

RTXO	2×10^{-9}rms	0.002 ppm
TCXO	1×10^{-9}rms	0.001 ppm
OCXO, on/off	5×10^{-10}rms	0.0005 ppm
OCXO, prop.	1×10^{-11}rms	0.00001 ppm

Long-term stability

The long-term stability of the time base clock oscillator is due largely to crystal aging. The nature of the crystal, the quality of the crystal, and the plane from which the particular resonator was cut from the original quartz crystal are determining factors in defining aging. This figure is usually given in terms of frequency units per month.

RTXO	3×10^{-7}/month	0.3 ppm
TXCO	1×10^{-7}/month	0.1 ppm
OCXO, on/off	1×10^{-7}/month	0.1 ppm
OCXO, prop.	1.5×10^{-8}/month	0.015 ppm
OXCO, prop.	5×10^{-10}/day	0.0005 ppm

Feedback oscillators

A feedback oscillator, **Fig. 5**, consists of an amplifier, A1, with an open-loop gain of A_{vol} and a feedback network with a gain –or transfer function – β. It is called a 'feedback oscillator' because the output signal of the amplifier is fed back to the amplifier's own input by way of the feedback network.

Figure 5 is a block diagram model of the feedback oscillator. That it bears more than a superficial resemblance to a feedback amplifier is no coincidence. Indeed, as anyone who has misdesigned or misconstructed an amplifier knows all too well, a feedback oscillator is an amplifier in which special conditions prevail. These conditions are called Barkhausen's criteria for oscillation:

- Feedback voltage must be in-phase – at 360° – with the input voltage.
- Loop gain βA_{vol} must be unity (1).

The first of these criteria means that the total phase shift from the input of the amplifier, to the output of the amplifier, around the loop back to the input, must be 360°, i.e. 2π radians, or an integer (N) multiple of 360°, i.e. $N2\pi$ radians.

The amplifier can be any of many different devices. In some circuits it will be a common-emitter bipolar transistor, either n-p-n or p-n-p. In others it will be a junction field-effect transistor (JFET) or metal-oxide semiconductor field effect transistor (MOSFET). In older equipment it was a vacuum tube.

In modern circuits the active device will probably be either an integrated circuit operational amplifier, or some other form of linear IC amplifier.

The amplifier is most frequently an inverting type, so the output is out of phase with the input by 180°. As a result, in order to obtain the required 360° phase shift, an additional phase shift of 180° must be provided in the feedback network at the frequency of oscillation only. If the network is designed to produce this phase shift at only one frequency, then the oscillator will produce a sine wave output on that frequency.

In Fig. 5 you can see that:

$$V_i=V_{in}+V_F \quad (1)$$

So,

$$V_{in}=V_i-V_F \quad (2)$$

and also,

$$V_F=\beta V_O \quad (3)$$

$$V_O=V_iA_{VOL} \quad (4)$$

The transfer function (or gain) A_v is:

$$A_V=\frac{V_O}{V_{IN}} \quad (5)$$

Substituting equations (2) and (4) into equation (5),

$$A_V=\frac{V_iA_{vol}}{V_i-V_F} \quad (6)$$

From equation (3), $V_F=\beta V_o$, so

$$A_V=\frac{V_iA_{vol}}{V_i-\beta V_O} \quad (7)$$

But equation 4 shows that $V_o = V_i A_{vol}$, so equation (7) can be written,

$$A_V = \frac{V_i A_{vol}}{V_i - \beta V_i A_{vol}} \qquad (8)$$

and, dividing both numerator and denominator by V_i,

$$A_V = \frac{A_{vol}}{1 - \beta A_{vol}} \qquad (9)$$

Equation (9) serves for both feedback amplifiers and oscillators. But in the special case of an oscillator $V_{in}=0$, so $V_o \rightarrow \infty$. Implied, therefore, is that the denominator of Equation (9) must also be zero,

$$1 - \beta A_{vol} = 0 \qquad (10)$$

Therefore, for the case of the feedback oscillator,

$$\beta A_{vol} = 1 \qquad (11)$$

The term βA_{vol} is the loop gain of the amplifier and feedback network, so equation (11) meets Barkhausen's second criterion. Thus, when these conditions are met the circuit will oscillate. Hopefully, what we intended to design was an oscillator, and not an amplifier.

In a crystal oscillator, amplified noise in the circuit at start up initiates the crystal oscillation, but it is the feedback voltage that is used to continuously 're-ping' the crystal to keep it oscillating.

General types of rf oscillator circuits

There are several different configurations for RF oscillators, but the fundamental forms are Colpitts and Hartley. **Figure 6** shows the basic difference between these two oscillators. Keep in mind that these are block diagrams, not circuit diagrams, so the apparent 'short' through the coil from the output to ground is not a problem here – there is no DC.

The Colpitts oscillator is shown in Fig. **6a)**. The oscillator is tuned by the resonance between inductor L_1 and the combined capacitance of C_1 and C_2 in series. In actual oscillators there will also be a tuning capacitor in parallel with L_1, and the total capacitance used in resonance will include the tuning capacitance, plus C_1 and C_2 in series.

The characteristic that distinguishes the Colpitts oscillator is that the feedback network consists of a tapped capacitive voltage divider, C_1/C_2. Output from this voltage divider is fed back to the input of amplifier A1.

A special variation on the Colpitts theme is the Clapp oscillator. The difference is that the Colpitts uses parallel resonant tuning, while the Clapp uses series-resonant tuning. Otherwise, they are identical – both use the capacitive voltage divider. Both variations on the Colpitts theme find extensive use in RF crystal oscillator circuits.

The Hartley oscillator is shown in Fig. **6b)**. Here, the tuning is done by an *LC* network, as in other RF oscillators, consisting of L_1 and C_1. The Hartley oscillator is identified by the fact that tapping the tuning inductor L_1 derives the feedback voltage.

Variations on the Hartley theme use a tapped coil as part of the feedback network, but a crystal to actually set the frequency of oscillation.

Colpitts crystal oscillator circuit

Figure 7 shows a basic Colpitts oscillator circuit. The active element is an n-p-n bipolar transistor, although in circuits to be discussed later FET and IC versions will be shown.

The transistor's DC bias is derived from resistor R_1 connected between V+ and the transistor base terminal. The crystal resonator is connected from the base to ground on

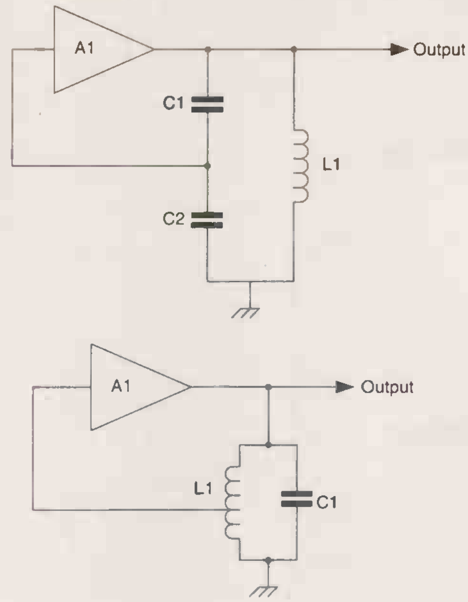


Fig. 6. In the Colpitts oscillator, L_1 and $C_{1,2}$ combined determine resonance, a). In the Hartley oscillator, b), tuning is determined by L_1 and C_1.

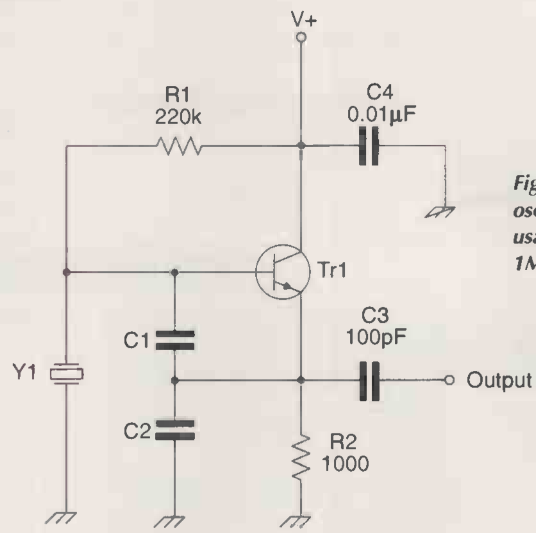


Fig. 7. Colpitts oscillator. This circuit is usable from about 1MHz to 18MHz or so.

this common emitter circuit. This circuit is usable from about 1MHz to 18MHz or so.

The circuit of Fig. 7 is a Colpitts oscillator, so uses a capacitive voltage divider, C_1 and C_2, for the feedback network. When this circuit is initially turned on, current will begin to flow collector-to-emitter. When this current first flows the crystal is electrically pinged, so will begin to oscillate.

Following initial start-up, a sample of the signal at the emitter is fed to C_1/C_2, and from there to the base. Because the emitter AC signal voltage is in phase with the base signal voltage, the Barkhausen requirements are met.

Some experimentation will yield the optimum values of C_1, C_2 and R_2 to ensure proper starting and running. The general rule for R_1 is to use the lowest value that will permit sure starting when the circuit is powered up.

There seems to be two approaches to finding values for C_1 and C_2 presented in the literature, but both assume that the total capactive reactance of the two capacitors in series is 300Ω. In one scheme, the initial trial values require $C_1=C_2$, while in other recommendations $C_2= 3C_1$ or $4C_1$. ■

In a second article on this topic, Joe takes a look at practical crystal oscillator circuits, including additional Colpitts variants, overtone oscillators and other forms.

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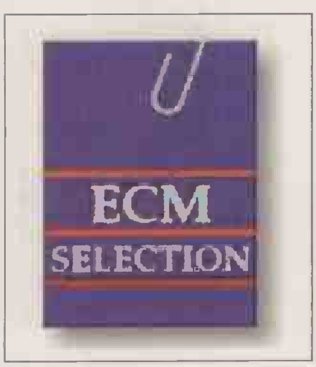

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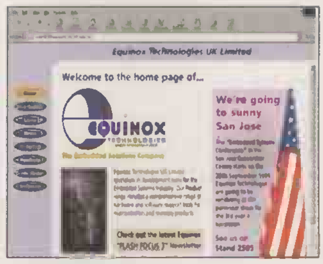

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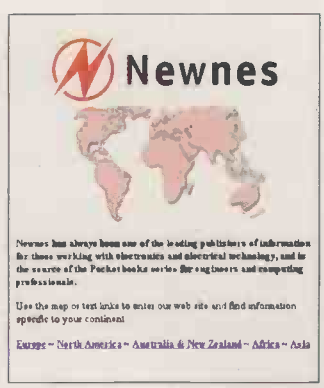

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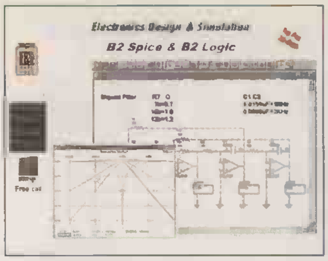

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Intruder alarm technology

Joe Cieszynski looks at the technology used in modern security alarm systems.

I was approached recently by a person who was concerned for the security of a number of valuable classic cars. He asked if I could, "...rig up some sort of alarm". I replied "Of course. How about a few trip wires fastened to Coke cans full of marbles?" He looked somewhat rebuffed. "Ah!", I went on, "you would like me to install a security system".

The point is, modern security alarm equipment is sophisticated and has many capabilities, but like any complex electronic equipment, it must be correctly installed for it to function reliably. Here, I examine the elements of the modern security alarm system, and see how technology has risen to the tough demands made by the hostile environment in which the security alarm exists.

This article looks at the heart of the system, the control equipment, starting with the topic of surveying.

Surveying

The solution to the security needs of one premises is not necessarily going to meet the needs of another, so before you can even think of purchasing any alarm equipment for an installation, you must first decide what you actually require.

The best way to survey a premises is to go outside, look at it, and try to view it from the standpoint of an intruder. Consider, "If I were going to break into here, how would I do it". Remember, intruders don't care how much damage they inflict on the premises; they are more concerned about being able to work undisturbed, and finding the easiest way in.

Once you have decided on the areas that you want to protect, and how you intend to protect them, you next have to consider entry/exit routes, part setting requirements, etc. This established, you are ready to select a control panel suitable to meet your requirements.

Now all that is left to do is install your cables, fit the detectors and sounders, connect up the control panel, install a 230V mains supply, program the panel, commission the system, test it, and show all the potential operators how it functions.

Alarm signalling

For many years the industry relied on the digital communicator. This had a plug-on NVM chip that contained the address of the premises. The disadvantage was that it had to have its own outgoing only calls phone line, otherwise it could be jammed by an incoming call.

The most popular form of communication is the BT RedCare service. Here a Subscriber Terminal Unit, or STU, is connected between the alarm and the BT line. The STU can convey much detailed information to the monitoring station, and the system can even map the progress of an intruder through the premises. The system is constantly monitored for a cut phone line.

A rival to RedCare is the Vodaphone Paknet System. Here the alarm is linked to a transmitter. The transmitter is polled every few minutes to ensure that it is still active. This is to prevent any attempt to jam the system.

Dualcom is fast becoming the preferred norm for remote signalling. Here a single unit containing both RedCare and Paknet is employed. If either system fails, the monitoring station can determine if it is a fault or an attack by looking at the data coming from the still active link. Dualcom has greatly cut the number of unnecessary police call-outs.

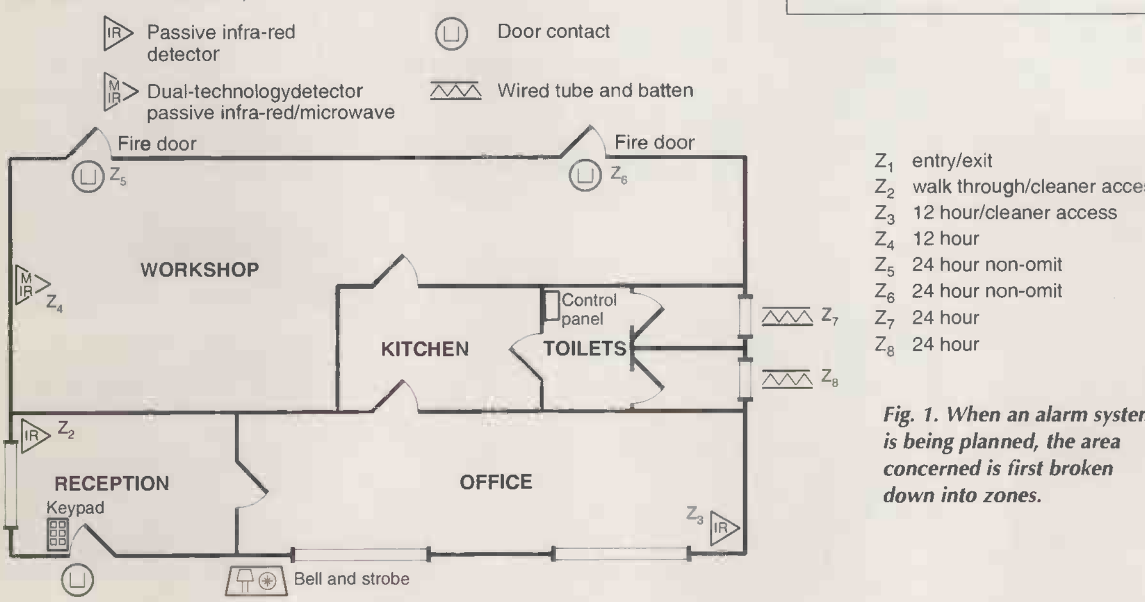

Fig. 1. When an alarm system is being planned, the area concerned is first broken down into zones.

The control panel

The security system engineer is not interested in the circuit operation of the control panel its self. For an electronics engineer, this can be frustrating, and the frustration is further compounded by the fact that manufacturers of security equipment do not release circuit diagrams of their equipment. This is partly for security reasons, but also it is to prevent bogus persons from copying designs and producing their own versions.

Alarm-zone inputs

The detection circuits are called *zones*. On a conventional panel, the detection device presents a closed switch across the zone terminals under normal conditions, opening the switch when an activation occurs. Normally closed operation is chosen so that the circuit is automatically monitored for breaks or high resistance connections.

On simpler control panels the response of the zones to an intrusion is programmed into the CPU by the manufacturer and cannot be altered. More up-market panels permit the installer to individually programme the zone responses, customising the panel to the premises.

Some common responses are *Entry/Exit*, where any number of zones can be assigned to this function; *24 hour*, where a zone is always active; *Walkthrough*, where a zone will not respond when an entry zone has been activated, but will otherwise signal an alarm; *Part Set Active*, which determines which zones are active when only part of the system is to be set; *Cleaner Access*, where entry of a different (cleaner) code will only disable certain zones; *Omit Permit*, determines if the customer will be allowed to omit a zone from the system. This last feature is used to prevent high security areas from being left unprotected. Typical applications of these zone responses (attributes) are illustrated in **Fig. 1**, which depicts a modest system in a small factory unit.

The walkthrough on zone 2 permits the user to access the keypad after entering the building, but an intruder coming into the room directly through the window would cause an immediate alarm response. Zones 2 and 3 will be 'off' when a cleaner code is entered.

Zones 5 and 6 are active 24 hours to prevent anyone either entering or exiting the premises through the fire doors unnoticed, these zones are also prevented from being omitted. Omitting a zone takes it out of the system until the system is unset and set once more.

Zones 7 and 8 are permanently active, 24 hours a day. This is common for window foil. In the event of the foil being damaged during the day, the customer will know immediately and have time to take action. This is better than discovering the fault when setting the alarm at home time!

In theory there is no limit to the number of detectors that can be connected to a zone. After all, it is just a number of switches connected in series.

In practice it is highly recommended that you connect just one detector to each zone. Firstly, this allows quick identification of an activated area. Secondly it makes fault location very much simpler.

Imagine having an intermittent fault on a zone that has, say, ten detectors connected to it. Where would you start? Perhaps it is not so bad if the system is installed in your own home, but when it is fifteen miles away, how many times do you fancy calling back out to sort the trouble?

Tamper inputs

BS4737 requires that all cables and device covers are protected by a permanent circuit to prevent tampering when the system is unset. So each device contains an anti-tamper switch. This switch is connected to a monitor on the control panel, which is active around the clock.

If the tamper circuit has just one set of terminals, all tamper switches must be connected *in series* to these terminals using terminal block or crimp connectors. This type of tamper connection is known as *global tamper*.

The disadvantage of such a tamper loop is that the control panel is unable to indicate which tamper switch has opened, making faults difficult to locate, especially if they are intermittent. Global tamper is used on smaller panels because it reduces both the physical size of the PCB, and the cost of manufacture.

More expensive panels will have an individual tamper circuit for each zone, allowing precise indication of tamper activations.

Zone circuits are said to be 'positive', and tamper circuits 'negative'. This somewhat ambiguous terminology is clarified in **Fig. 2** which illustrates the operating principle of the input circuits.

The zone inputs are pulled up to the +12V supply, whereas the tamper inputs are pulled to 0V. There is a very good reason for doing this. Security alarm equipment is designed to be as difficult as possible to defeat, and one vulnerable part of the system is the cables.

By refraining from using a standard colour code throughout the industry, it is difficult for someone to cut into the cable and attempt to short out the zone cores.

Opposite polarity circuits makes the task even more difficult. Should someone connect the zone to the tamper circuit by mistake, the +12V will be removed and the system will see an alarm condition on that zone. If this occurs when the system is unset, nothing will happen immediately, however when the customer attempts to set the system it will show an alarm fault in that zone, and the system will not set.

Other inputs

Typically, Fire, Personal Attack, and Auxiliary Tamper inputs may be available.

The fire input is particularly useful in domestic premises. A 12V smoke detector can be connected to this input and monitored around the clock. When an activation occurs, the internal

Multiplexed alarm systems

It is not practical to manufacture an alarm panel with more than eight zones. Yet many industrial premises require hundreds of zones to provide adequate cover. The answer is to use multiplexing.

The most common multiplex uses collector points which communicate with the main panel via a data wire. Each collector point will have provision for four or five detectors. An LCD display at the control panel will clearly communicate the location of an activation to the user.

Another form of multiplex is the ID system developed by ADE. This requires the insertion of a small three leg chip into each detector. The chips all have an ID code, and the panel addresses each chip individually to determine the condition of the detector. Detectors can be connected daisy chain fashion along a single four core cable.

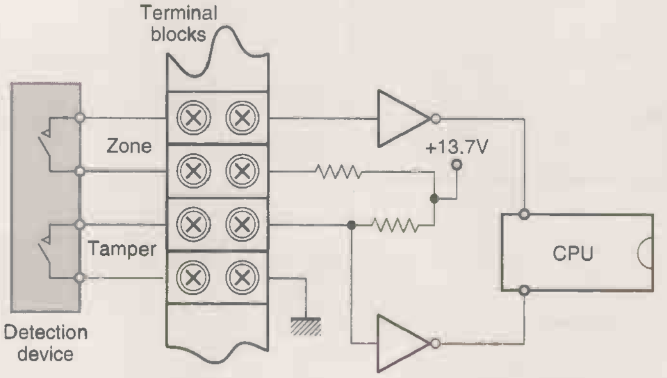

Fig. 2. In intruder alarm terminology, zone circuits are said to be 'positive', and tamper circuits 'negative' – zone inputs are pulled up to the +12V supply, whereas the tamper inputs are pulled to 0V.

sounders are triggered, but with a different sound.

The main advantage of using an alarm system smoke detector instead of a battery operated alternative is that you do not have to remember to replace the battery periodically. Apparently, despite the fact that battery smoke alarms have a 'low battery' warning, many people remove the battery to stop the annoying 'beep', and subsequently forget to replace it.

However, an intruder control panel must never be used as a primary fire alarm system as it does not comply with the stringent regulations that govern fire alarm equipment.

The Personal Attack input is another round-the-clock circuit which is connected to the positive supply like a zone input. It may have an attribute known as 'Bell Delay'. This means that when the PA button is depressed, the local sounders will not activate for a few minutes. This is helpful in places like banks where an immediate sounder activation could provoke or 'spook' armed robbers into doing something rash.

The delay period allows time for the remote signalling equipment – some form of modem – to contact the monitoring station.

Auxiliary tamper would be used to connect any other tamper switches that are not on the zones; i.e., tamper switches on remote power supply covers, signalling equipment covers, etc.

Output facilities

If asked to name an output from an intruder alarm control panel, perhaps the most obvious one would be the bell. However there's a number of other outputs. Typical outputs on a smaller panel are *Bell, Strobe, P1/P2* and *Speaker*.

With the exception of the speaker output, all of the outputs are actually nothing more than a switch that can be used to activate other electronic devices. The principle is illustrated in Fig. 3. Depending on the output type, the transistor will be normally on or normally off, changing states to activate the device.

The terms *"Negative Removed"* and *"Negative Applied"* are commonly used to define the output type. For example, if the transistor is normally conducting, then the output would be described as a "Negative Removed" type. That is, the transistor is turned off when the output is activated. In some cases the output type can be programmed by the engineer.

The bell output will be like that shown in Fig. 3. However, the CPU action in the event of an alarm activation will have to be programmed by the installation engineer. For example, do you require immediate or delayed bells? Do you only want a delay when the PA is activated? Some sounder units require a negative applied activation while others require negative removed.

And finally, in the UK it is a requirement that all alarm sounders cut off after 20 minutes maximum. Failure to comply with this may lead to prosecution by the local environmental health department.

The strobe unit is self contained, and simply requires application of 12V. Unlike the bell output, this does not usually have any programmable options.

Programmable outputs, often labelled P1, P2, etc., are outputs that can be either positively or negatively applied or removed. Some examples of their application are...

- Toggle at bell activation; to switch on a speech dialler or 230V security lights, via a 12V relay.
- Toggle before bell activation; where bell delay is used, the output could still trigger a security VCR.
- Toggle upon re-setting of the alarm to re-set latching detectors.

The speaker output is generally driven by a low power audio output stage comprising a class A output stage or a chip, fed by a multi-tone oscillator. Most manufacturers specify the use of 16Ω speakers. This is to allow the use of up to four speakers without damaging the output stage.

The keypad

There is nothing special about the keypad from an electronics point of view, however when designing a system, the type and location of the keypad(s) is an important consideration.

The cheapest control panels have an integral keypad with an LED display – seven segment at best. But you may prefer to use an end station with remote keypads. This means that the large control panel does not have to be at the front door. Perhaps more importantly, you don't have the problem of trying to hide a large cluster of cables in the hallway.

There is also a half-way option where the control panel has an integral keypad with the option of fitting more – usually up to four.

The display type is also important. It is far easier to program a panel employing an LCD because it is able to talk back to you. It is also much simpler for the user to identify the zone in the event of an activation when the display reads 'Lounge window contact' rather than an LED with 'Zone 3' written alongside.

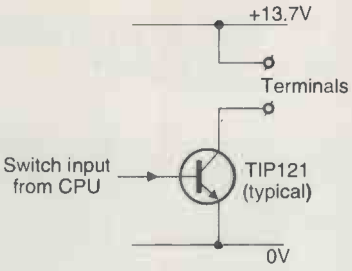

Fig. 3. With the exception of the speaker output, all of the outputs in a typical alarm system are nothing more than a switch used to activate other electronic devices.

On the other hand, LCD keypads are much more expensive than their LED counterparts.

The keypad may require four or six wires, depending on whether the tamper switch is wired directly back to the panel, or to the on-board chip. In a four wire arrangement, two wires carry the 12V supply, the third is the data wire, and the fourth carries a clock signal from the main CPU.

Using the one clock removes synchronisation problems. To prevent data corruption it is generally recommended that the keypad cable is kept separate from other cables in the system – i.e., don't incorporate the keypad data in a 12-core multicore cable. Where the keypad cable must run through areas of high RFI or EMI, screened cable should be used.

Extra control panel features

A list of additional control-panel features could be endless if we were considering the broader aspects of security alarm systems. In the budget range covered here though, the most you will most probably get is an *event log*, a printer port, and a socket labelled '*Comms*'.

Event logs are very useful for tracing false alarms. Unfortunately many of the cheaper panels only have a very small memory area allotted for this, giving just ten or twenty most recent events.

For such a feature to be of any real use you require at least two hundred events to be logged, which does not go back very far when you consider that a good log should record not just alarm activations, but also set/unset times and dates.

The printer is useful for obtaining a hard copy of either the event log or the engineer programming. Unfortunately many manufacturers use their own customised printer that comes with a hefty price tag. However more and more panels are beginning to interface with a standard PC printer.

The 'Comms' output is the communicator output. This would be connected to some form of modem that will signal to a central monitoring station in the event of an alarm activation. This is a subject in its own right and is out of the range of this article. ■

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