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NOVEMBER 2003 £3.25

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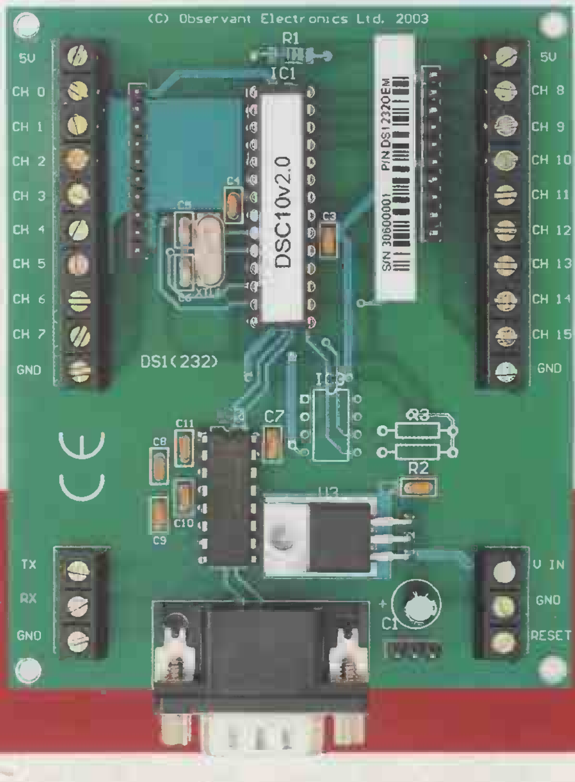

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NOVEMBER 2003 VOLUME 109 NUMBER 1811

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Control the speed of almost any common DC motor rated up to 100V/5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15VDC. Box supplied. Dimensions (mm): 60Wx100Lx60H.
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Drives any 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps max. Provides speed and direction control. Operates in stand-alone or PC-controlled mode. Up to six 3179 driver boards can be connected to a single parallel port. Supply: 9V DC. PCB: 80x50mm.
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Independently control two unipolar stepper motors (each rated up to 3 Amps max.) using PC parallel port and software interface provided. Four digital inputs available for monitoring external switches and other inputs. Software provides three run modes and will half-step, single-step or manual-step motors. Complete unit neatly housed in an extended D-shell case. All components, case, documentation and software are supplied (stepper motors are NOT provided). Dimensions (mm): 55Wx70Lx15H.
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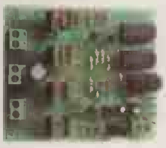
Assembled Order Code: AS3113 - **£24.95**

NEW! Bi-Polar Stepper Motor Driver

Drive any bi-polar stepper motor using externally supplied 5V levels for stepping and direction control. These usually come from software running on a computer.
Supply: 8-30V DC. PCB: 75x85mm.
Kit Order Code: 3158KT - **£12.95**
Assembled Order Code: AS3158 - **£26.95**

Most items are available in kit form (KT suffix) or assembled and ready for use (AS prefix).

Controllers & Loggers

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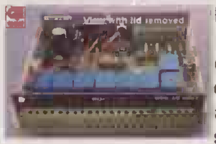
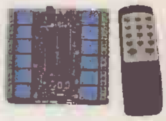
Kit Order Code: 3145KT - **£22.95**
Assembled Order Code: AS3145 - **£29.95**
Additional DS1820 Sensors - **£3.95 each**

NEW! DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, Rings to Answer, Auto Hang-up and Lockout. Includes plastic case. 130x110x30mm. Power: 12VDC.
Kit Order Code: 3140KT - **£39.95**
Assembled Order Code: AS3140 - **£59.95**

Serial Isolated I/O Module

PC controlled 8-Relay Board. 115/250V relay outputs and 4 isolated digital inputs. Useful in a variety of control and sensing applications. Uses PC serial port for programming (using our new Windows interface or batch files). Once programmed unit can operate without PC. Includes plastic case 130x100x30mm. Power: 12VDC/500mA.
Kit Order Code: 3108KT - **£54.95**
Assembled Order Code: AS3108 - **£64.95**

Infrared RC Relay Board

Individually control 12 on-board relays with included infrared remote control unit. Toggle or momentary. 15m+ range. 112x122mm. Supply: 12VDC/0.5A
Kit Order Code: 3142KT - **£41.95**
Assembled Order Code: AS3142 - **£59.95**

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We have a wide range of low cost PIC and ATMEL Programmers. Complete range and documentation available from our web site.

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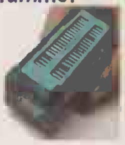
NEW! USB 'All-Flash' PIC Programmer

USB PIC programmer for all 'Flash' devices. No external power supply making it truly portable. Supplied complete with 40-pin wide-slot ZIF socket, box and Windows Software.
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Assembled Order Code: AS3128 - **£54.95**

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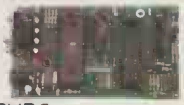
Will program virtually ALL 8 to 40 pin PICs plus a range of ATMEL AVR, SCENIX SX and EEPROM 24C devices. Also supports In System Programming (ISP) for PIC and ATMEL AVRs. Free software. Blank chip auto detect for super fast bulk programming. Requires a 40-pin wide ZIF socket (not included).
Kit Order Code: 3144KT - **£54.95**
Assembled Order Code: AS3144 - **£59.95**

ATMEL 89xxxx Programmer

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. Supply: 16-18VDC.
Kit Order Code: 3123KT - **£29.95**
Assembled Order Code: AS3123 - **£34.95**

NEW! USB & Serial Port PIC Programmer

USB/Serial connection. Ideal for field use. Header cable for ICSP. Free Windows software. See website for PICs supported. ZIF socket not incl. Supply: 18VDC.
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Assembled Order Code: AS3149 - **£44.95**

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Wireless, wireless everywhere......

And half of it doesn't work. I reported a few months ago about the trouble I was having with getting a simple Bluetooth connection going between my laptop and a GPRS phone. Well, I have to admit defeat – the Nokia and Belkin softwares combine to be the most hideous piece of code and I'm now using infra-red.

The point of this, as I said at the time, is that we as engineers need to make this kind of technology accessible to the average member of the public for it to be successful, so that lots of people buy it and in the long term to keep us all in a job.

I've just had a similar 'radio' experience by putting in a Wi-Fi network at home. In fact, setting up the network and even the ADSL router was extremely easy. The software and instructions from the 'black box' maker (D-Link) and the installation instructions from my ISP (Pipex) combined on this occasion to make the project go very smoothly.

I look forward to more 'public' Wi-Fi points opening up in the future – although the small bandwidth allocated thus far is getting very cluttered. It will be wonderful, though in the not too distant future to be able to hook up to a proper, high-speed network, just using the adaptor in the laptop as opposed to hooking into other (not very reliable) networks. The hugely indebted G3 franchise holders could also learn a lesson or two. Whilst they are scrabbling around looking for a 'killer app' – the business community needs high-speed data on the move and is willing to pay for it. Sending your mates stupid videos or watching sports highlights on the phone is not going to do repay the huge fees these networks have had to shell out to unscrupulous governments selling off bandwidth. But the plus side is that the proliferation of all this mobile networking can only help our industry back on its feet.

More housekeeping

As I reported last month, we are still experiencing problems with our admin without a new 'Jackie'. Readers who have been waiting for our offers will be pleased to hear that they have all been dispatched (in fact, by the time you read this I will be sunning myself in Rhodes and you will have received your goods. And of course look out for a new reader offer for those who were unlucky in our competition last month. You can buy an Observant Datastation development kit for £20 off (see page 42).

Phil Reed

New editorial and advertising address

The Highbury Business Communications office previously at Cheam, Surrey has moved to Swanley in Kent. All correspondence intended for the editorial and advertising departments should be addressed to:

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Nexus House,
Azalea Drive,
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Kent, BR8 8HU

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01322 660 070
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Electronics World is published monthly. Orders, payments and general correspondence to **Jackie Lowe, Highbury Business Communications, Nexus House, Azalea Drive, Swanley, Kent, BR8 8HU**

Newstrade: Distributed by COMAG, Tavistock Road, West Drayton, Middlesex, UB7 7QE Tel 01895 444055.

Subscriptions: Wyvern Subscription Services, Link House, 8 Bartholomew's Walk, Ely Cambridge, CB7 4ZD. Telephone 01353 654431. Please notify change of address.

Subscription rates
1 year UK £38.95 O/S £64.50
US$100.62 Euro 102.55

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16MW switch is fastest yet

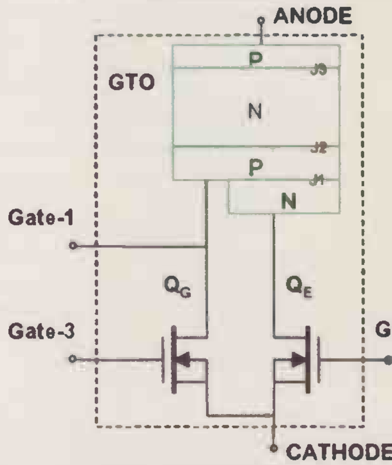
Researchers at the US Virginia Tech have developed a high-power semiconductor switch.

Called an emitter turn-off thyristor (ETO), it operates without snubber circuits and can be controlled fibre-optically.

"An optical pulse is applied to turn on current flow. It can conduct 10,000 amps of current and will withstand 16MW of instantaneous power," said Professor Alex Huang of Virginia's electrical engineering department.

For continuous operation, the ETO can carry 1.5kA (at 125°C) and block 6kV. Switching time is 5μs, on or off. "This switch allows us to advance very high power converters from a line speed of 60Hz to 3kHz switching at the same power level," said Huang. "This speed allows you to chop the voltage into whatever shape you need."

Present technology is the GTO (gate turn-off thyristor). "The GTO is reliable and inexpensive, but requires a snubber capacitor to protect it in the turn-off process." said Virginia, "The snubber uses significant power itself and increases the size of the switch."



The ETO is a hybrid made from a GTO (gate turn-off thyristor) and mosfets (insulated gate bipolar transistors). The two mosfets operate as a complementary pair to assist GTO turn-off. Q_E, the emitter switch, is turned off and the gate switch Q_G is turned on. This diverts the GTO cathode current to its gate forcing the 'unity gain turn-off' - where all the minority charges in the p-base region are extracted quickly. In practice there are multiple mosfets in both positions and a single large GTO.

UK lags in Pb-free race

The British electronics industry has its head in the sand over the ban on lead-based solders and components, said ERA Technology.

The Surrey-based research firm has surveyed the UK electronics industry to find how ready it is to make the transition from tin/lead solders to lead-free solders, and lead-free components

"Only three per cent of companies have developed lead-free products, only nine per cent of companies have started trials with lead-free solders and 50 per cent of companies admit they don't understand the impact of banning lead-based solders," said ERA.

The EU 'Restriction of use of certain Hazardous Substances' (RoHS) directive bans lead from many finished electronic and electrical products from July 1st 2006.

"While the deadline may seem a long way off, there are currently no lead-free solders that are direct replacements for use in all existing products," said ERA, "All lead-free solders are different in their properties and the way they need to be used."

Over 150 small, medium and large size companies were questioned by ERA. "These were a broad cross-section of the country's electronics industry, which means the findings are truly representative," said ERA. "The good news is that 87 per cent of the sample at least knew about the RoHS directive, and half had contacted one supplier."

www.era.co.uk/product/lead-free-survey.htm to buy the report.

Casimir force measured

Physicists in the US have made a more accurate measurement of the Casimir force, that pushes together objects at close separations. The work could result in better photonic mirrors and nanomachines.

"The Casimir force is not a new discovery," said Purdue University's Professor Ephraim Fischbach. "Its effects on machines are essentially negligible until you start building at the nanoscale. When the teeth of two tiny gears come together, for example, the Casimir force could push them together so strongly that they would stick and freeze up."

First predicted by Hendrik Casimir of Philips Research Labs in 1948, the force is due to the fact that objects close together cannot fit any photons, real or virtual, between them. Thus photons striking the outside of the objects push them together.

In experiments the forces have been measured at up to 1nanonewton, or 100μ dynes. Purdue's work has proven the theory within one per cent of experiment, which should lead to better modelling.

"It is not often you get to unify theory and practice this closely," said Fischbach.

Robot swarm maps and searches

US research institute SRI has made 100 Centibots to map and search unknown spaces.

"As totally self-contained, untethered entities, these robots can determine their own location and plan their own path, process images they see, make decisions based on a continually expanding knowledge base, and negotiate with other robots when teamwork is required," said SRI's Artificial Intelligence Center.

There are two types of Centibot. Mapping robots with laser range finders enter an area first, followed by a larger second wave of tracking robots that search.

As they move, the robots create an adhoc 802.11 (WiFi) network to enable all machines to stay in touch with the control centre which directs the swarm.

The robots run the Debian distribution of Linux and use a software control system developed the Artificial Intelligence Center that was first created as an integrated architecture for robot perception and action.

Processing power comes from 1GHz mini-ITX size PC motherboards from VIA - which recently launched a Robotics Initiative "in response to the inexorable melding of mechanical robots and the PC architecture", it said.

The Centibots project is sponsored by the US military Defense Advanced Research Projects Agency (DARPA).

www.ai.sri.com/centibots
www.viaarena.com

UK starts ceramic antenna research

Leatherhead technology firm ERA Technology has begun a research programme on antenna technology using ceramic structures.

"The new technology will combine the efficiency and bandwidth of conventional antennas with the compactness of current ceramic designs," said the firm.

ERA will use the low temperature co-fired ceramic (LTCC) process to create complex 3D structures.

The technique could also lead to low cost phased arrays, said the firm, by combining conductors and active circuits in the same ceramic block.

"This new technology is a real breakthrough because of its versatility, compact size and low manufacturing cost," said Dr Robert Pearson, head of ERA's antenna business.

"In military applications, it offers favourable radar and electromagnetic compatibility characteristics and therefore can be used as a fundamental building block on a range of future military platforms. As a bonus, the construction technique also offers exceptionally high temperature performance, making it ideal for fast jets and missiles.

Operating bandwidths will be better than ten per cent, claimed ERA, while the antennas could be configured as multiband devices.

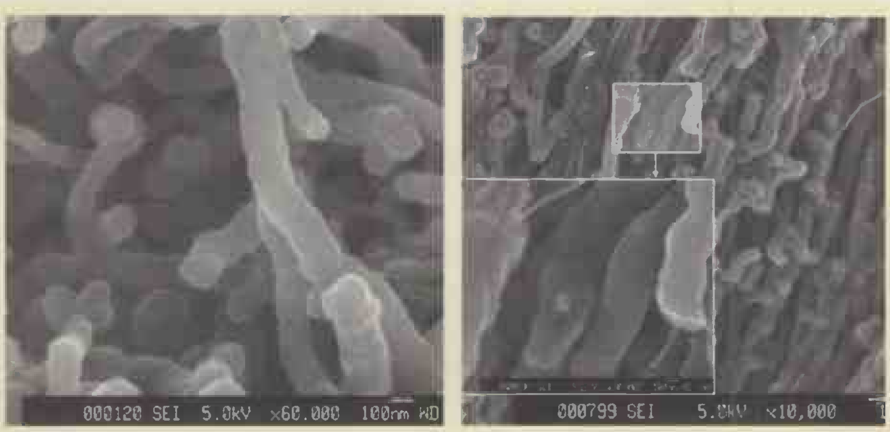
A Cambridge University researcher has found that coating carbon nanotubes with conducting polymers could lead to supercapacitors that rival existing technology.

Dr Mark Hughes from the department of materials science and metallurgy found that both of the two materials have desirable properties and has worked on merging them.

Carbon nanotubes have high conductivity and a large surface area, while the conducting polymers, such as polypyrrole, can be oxidised and reduced easily and quickly, allowing many charge and discharge cycles.

When combines, these two materials offer a high capacitance material of more than 2.6Fcm^2.

The capacitance is more than double that of either material on its own, said Hughes.



These SEM images show (a) randomly oriented and (b) aligned composites of carbon nanotubes and polypyrrole.

Second-generation DRM broadcast receiver

A second-generation DRM (Digital Radio Mondiale) receiver has been announced by Coding Technologies.

A joint venture with Munich-based product design house Mayah, the radio is smaller (21 x 7 x 13cm) than the 29 x 7 x 19cm ¤1,000 first-generation design, will be cheaper, said Coding, and also receives standard AM transmissions.

DRM is the digital transmission standard chosen by most of the world's broadcasters to replace analogue AM on shortwave, mediumwave and longwave.

Coding is the company behind the audio compression technology which makes it possible to fit good quality audio into the limited spectrum normally allocated to an AM broadcast channel - hence its interest in popularising the format by developing receivers. "Now that many radio stations already broadcast a full DRM programme daily, these first mass-produced receivers will open the path to the end consumer for affordable access to Digital Radio Mondiale broadcasts," said Coding.

Called Spectral Band Replication (SBR), Coding's technology allows a fictitious but realistic spectrum from 7kHz upwards to be generated from an audio signal low-pass filtered to below 7kHz, plus some 'helper' information.

Part of the helper information is the shape of the discarded upper spectrum and SBR generates harmonics of the low-pass filtered signal to fit the original upper spectrum profile. Other helper information describes significant signals above 7kHz which were not harmonically related to lower frequencies.

The sub 7kHz signal is compressed using standard MPEG 4 AAC audio compression.

The whole scheme is called aacPlus, where the Plus is SBR. "aacPlus delivers streaming and downloadable 5.1 multi-channel audio at 128Kbit/s, CD-quality stereo at 48Kbit/s, excellent quality stereo at 32kbit/s, and excellent quality for mixed content at 20Kbit/s mono and below," said Coding.

www.mayah.com
www.codingtechnologies.com

What does it sound like?

Electronics World heard a demonstration of aacPlus audio.

It is much more like the sound of FM on VHF or MP3-encoded material than AM on MW. The simulated upper frequencies don't sound synthetic to the casual listener - although more experienced people might of course be able to spot the difference between FM and aacPlus on MW.

Giant detector comes online

UK scientists have started receiving data from the 6,000 ton MINOS detector located in an iron mine in northern Minnesota.

Minos - the Main Injector Neutrino Oscillation Search - hopes to gain more understanding of the neutrino mass.

"The MINOS detector in Soudan, Minnesota, together with the new Fermilab neutrino beam line, will provide a detailed look at the secrets behind neutrino oscillations," said Dr Raymond Orbach, director of the US department of energy's office of science.

MINOS is over 30m in length and took more than four years to build. Its 486 steel plates are each about 7m high and are coated with scintillating plastic.

The detector is said to be able to tell the difference between neutrino and anti-neutrino interactions. Eventually neutrinos 'made' in Illinois will be sent through 450 miles of the earth directly to MINOS. Out of one trillion neutrinos per year, only about 1,500 will collide with an atomic nucleus in the detector.

Scientists hope to discover more about the three known types of neutrino - electron, muon and tau - and how they switch from one to another as they move through space and matter.

1kW output from fibre laser

A fibre optic laser with an output power exceeding 1kW has been developed by Southampton Photonics (SPI) and Southampton University's Optoelectronics Research Centre (ORC).

While higher power fibre lasers have been reported, these are (optically) less pure multi-mode systems.

"Breaking the kW barrier with a single fibre having high beam quality is a milestone thought to be virtually unattainable just a few years ago," said David Payne, SPI's chairman and director of the ORC.

SPI uses a cladding pump technique for its fibre lasers, which allows a multi-mode source to produce single-mode output. Light from a diode stack is launched into the inner cladding of a double-clad single-mode fibre. The pump light propagating through the inner cladding excites the rare-earth elements in the core, in this case ytterbium, producing single mode light at 1090nm.

The firm has quadrupled its output power of these lasers since February. It will produce commercial versions for industrial and aerospace applications.

FogScreen is a walk-through display made of fine mist. "The key features are that the screen is flat and thin, enabling high-quality projections," said the Finish firm. "It feels like nothing and does not make things wet.

Physics turns schoolkids off

A-level entries for physics and other science subjects have fallen again, according to figures from the Institute of Physics.

The number of students taking A-level physics dropped by three per cent this year.

On the positive side, said the IoP, the ten year trend which has seen entries dropping from 60,000 to 30,000 is slowing.

The IoP blamed subjects such as law and media studies for the declining fortunes of science subjects. In its promotion of the hard sciences it points to evidence that science graduates "have higher salaries than arts and humanities graduates in later life".

A shortage of physics teachers is being addressed by a £750,000 investment from the IoP in supporting development of teachers of 11 to 14-year olds.

Book-sized PC for servers

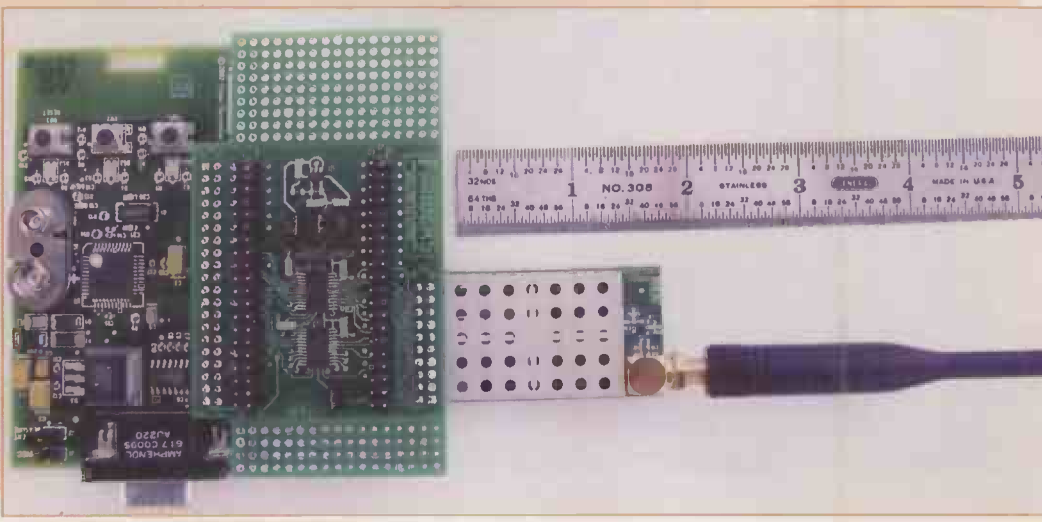
Taiwanese PC component maker VIA has introduced a new series of motherboards in the 17 x 17cm mini-ITX format, aimed at networked systems "enabling the development of a wide variety of networking applications including servers, firewalls, and routers", said VIA.

Called the EPIA CL-Series, the boards have dual 10/100 Mbit/s LAN controllers, six USB 2.0 connectors for peripherals, four serial COM ports for older peripherals, support for LVDS embedded LCD panels and a PCI slot for expansion.

The soldered-in processor is VIA's own x86-compatible range including the fanless 677MHz Eden (CL6000), the 800MHz C3 (CL8000) and the CL1000 that uses VIA's top-end 1GHz Nehemiah chip.

All boards have a hardware MPEG-2 decoder and integrated graphics core.

www.via.com.tw



Future Electronics is offering a development kit for low power radios using the 433, 868 and 915MHz frequencies. The radios make use of the Xemics XM1202 RF transceiver module and Motorola's '908 microcontroller. The combination allows 'drop-in' designs to be created that will meet FCC/CE/ETSI certification, said Future. The module takes RS232 data and transmits over the RF link at between 4.8kbit/s and 76.8kbit/s. Output power can be programmed up to 15dBm (31.5mW).

One step closer to SkyNet

US computer scientists are to test a prototype of Cyberinfrastructure, the technology which will eventually support its inter-supercomputer data grid.

The prototype, NPACI Grid, is from the US National Partnership for Advanced Computational Infrastructure and will connect its main resource sites: at the San Diego Supercomputer Center (SDSC), the Texas Advanced Computing Center (TACC) in Austin, TX, and the University of Michigan, Ann Arbor.

It will then be extended to the California Institute of Technology, Pasadena.

"NPACI Grid is a production, heterogeneous national Grid consisting of interoperable software, scientific applications, and hardware resources," said the organisation. "It unifies mature software infrastructure efforts through the development of the interoperable, tested and hardened 'NPACKage' deployed at all resource sites."

Other parts of Cyberinfrastructure development are US National Science Foundation's NSF Middleware Initiative (NMI) and TeraGrid/ETF project.

The hardware resources in the NPACI Grid are a 1.7Tflop AIX cluster, Blue Horizon at SDSC, a 435Gflop AMD based Linux cluster at the University of Michigan and three large shared-memory server nodes at TACC delivering 1.16Tflop.

Smart sand is more than silica

Grains of sand might be worth a second glance if research at five of Scotland's leading universities comes to fruition.

A team from the universities of Edinburgh, Glasgow, Napier, St Andrews and Strathclyde has just won a £1.3m grant to develop networked computers as small as sand grains.

The project, called Speckled Computing, aims to integrate modest amounts of digital signal processing, an RF transceiver, power source and sensors.

Professor DK Arvind, director of Edinburgh's Institute for Computing Systems Architecture, said the project will proceed in two stages: "The aim is to produce these specks in a millimetre cubed of semiconductor." There is an intermediate stage of $5mm^3$ in two years, with the final mm^3 in four years."

Although each device will not have large amounts of processing power, because they are networked they will form a distributed system.

Arvind said the power source will be a photovoltaic cell, made using a gallium arsenide process. The radio will also use GaAs, while digital sections will use CMOS. The two sections will be bonded together.

Qinetiq wins windfarm funding

Defence technology research firm Qinetiq has won funding from the DTI to develop 'stealthy' wind turbine blades.

Qinetiq hopes that by modifying their glass fibre reinforced polymer construction, it can reduce the unwanted radar reflections from the blades.

Air traffic control, marine navigation, weather monitoring and Ministry of Defence systems are all affected, it said.

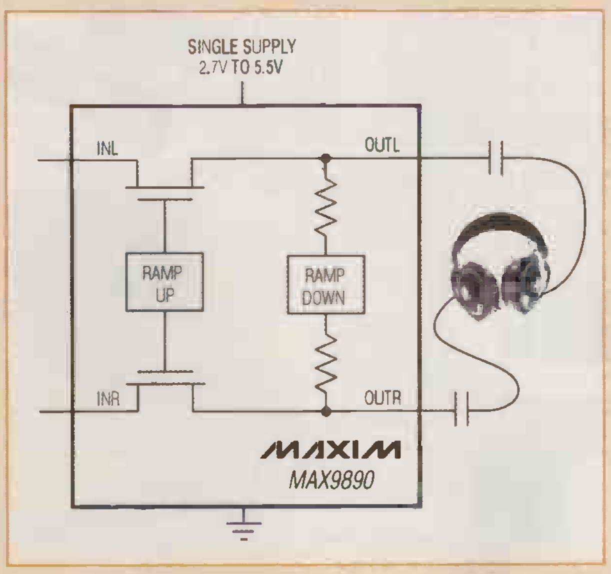
NOI Scotland with work with Qinetiq on the blades. The firm, originating from Germany, has technology for building 50m, resin-infused blades suited to offshore turbines producing 2MW more more.

"This is an excellent example of how the results of military research can be exploited for civil gain," said Steve Appleton, the QinetiQ technical leader of the DTI project.

The UK Government has set ambitious targets for clean energy production, with ten per cent of the countries energy to come from sustainable sources by 2010, and 20 per cent by 2020.

Despite our constant complaints about wind, the UK has only the eighth largest amount on installed wind generating power in the world at 570MW. Germany tops the list with 12,000MW, while the US has 4,700MW and Spain 5,000MW.

According to the British Wind Energy Association, last year over a quarter of all proposals for windfarm developments were the subject of objections from radar operators.



Chip de-thumps headphones

Maxim has revealed a novel chip which removes switch-on clicks and thumps from headphones.

The MAX9890, as it is called, is placed between amplifier and headphone socket and open-circuits both left and right paths until transients are under control.

The device requires only one additional $0.1\mu F$ capacitor and deals with switch-off transients as well.

Applications in portable equipment such as notebook, phones, DVD players and PDAs are foreseen, particularly where an existing model has a click problem, or the thump-prone audio amplifier is part of a larger chip which cannot be designed out.

There are two versions. The MAX9890A for use with DC-blocking capacitors of up to $100\mu F$ and the 9890B for capacitors up to $220\mu F$

Supply is 2.7V to 5.5V, 23dB of click-and-pop suppression is provided, supply current is $20\mu A$ and added THD+N is under 0.006% into a 32Ω load. Package is either 1.5 x 1.5 x 0.6mm (9-pin) or an 8-pin 3 x 3 x 0.8mm.

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RTTY Decoder

Radio Teletype (RTTY) is a direct machine-to-machine communications mode and has been in existence since the 1930's. The commercial use of RTTY on short wave has declined having been replaced with more robust transmission modes, however radio amateurs still use RTTY. Roger Thomas has designed an ingenious decoder

To encode and transmit text characters two different audio frequencies are transmitted. These two audio frequencies are commonly referred to 'mark' and 'space', where mark is usually the higher frequency. The most common audio frequencies used within Europe are 1275Hz (space) and 1445Hz (mark) and the difference between the two audio frequencies is called the 'shift'.

Most amateur radio transmissions use 170Hz audio shift, but shifts of 425Hz or 850Hz are used on other bands. It is possible for the transmission to be 'up side down' with the space frequency higher than the mark frequency, changing the receiver's side band settings and re-tuning will correct this. American amateur stations use a different set of audio frequencies (2125Hz and 2295Hz) but as the shift is still 170Hz this does not pose any problems with tuning or decoding.

Transmission speed is specified in baud, where baud is defined as the number of signal changes per second. Amateur RTTY transmissions in Europe are normally 45 or 50 baud but other speeds including 75 and 110 baud are used on other commercial bands. Although 45/50 baud transmission may seem very slow in comparison to computer modems, it is fast enough for a typed conversation. A 45/50 baud RTTY transmission equates to approximately 66 words per minute.

RTTY text characters are encoded using ITA2 (International Telegraph Alphabet Number 2) code, which uses five bits for each character. With only five bits per character, the maximum number of unique patterns is only 32. To enable RTTY to transmit the full alphabet two different character tables are used, one for letters (all letters are in upper case) and one for figures (which includes punctuation). A letters or figures control character determines which table to use when printing the received character. Control and space characters are represented in both tables to reduce then number of times the letters or figure control character needs to be transmitted. RTTY signals do not have any error detection capabilities.

RTTY is relatively simple to decode in software, but the different combinations of transmission speed and shift means that it is impossible to decode every combination. The PIC program as given is designed to decode both 45 and 50 baud RTTY using 170Hz shift as this is the most common amateur radio signal, but both speed and shift parameters can be changed within the program.

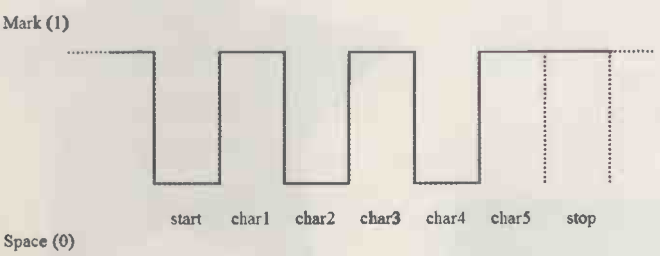


Fig. 1. RTTY Character 'Y' or '6'.

RTTY is an asynchronous mode, which means that there is no common time frame between the station transmitting text and station receiving. In front of every 5 bit character is a single start bit (at space frequency) that makes the receiving printer ready for the incoming transmission. The five character data bits are transmitted, followed by a 'stop bit' which may be of a longer duration (one or one and a half units) and is transmitted at mark frequency. A useful feature to overcome the problem of noise or corrupt characters incorrectly signifying use of the figure table is to automatically revert to the letters table on receiving a space character.

Using start/stop bits means that after the receiving printer had printed out a character it was then waiting for the start bit of the next character. Thus synchronisation is not needed between sender and receiver.

RTTY uses the ITA2 (International Telegraph Alphabet 2) character set, sometimes called Baudot code (named after Emile Baudot), and is listed in **Fig. 2.** Where there is no designated character assigned (figure shift F, G, H) I have used characters from the teleprinter set.

Fig. 2. RTTY text characters.

letter	figure	RTTY	value
A	-	00011	3
B	?	11001	2
C	:	11101	14
D	$	01001	9
E	3	00001	1
F	!	01101	13
G	&	11010	26
H	#	10100	20
I	8	00110	6
J	'	01011	11
K	(	01111	15
L	)	10010	18
M	.	11100	28
N	,	01100	12
O	9	11000	24
P	0	10110	22
Q	1	10111	23
R	4	01010	10
S	"	00101	5
T	5	10000	16
U	7	00111	7
V	=	11110	30
W	2	10011	19
X	/	11101	29
Y	6	10101	21
Z	+	10001	17

Fig. 3. RTTY control characters.

RTTY	function	value
11111	letters shift	31
11011	figures shift	27
01000	carriage return	8
00100	space	4
00010	line feed	2
00000	blank	0

RTTY software description

The advantage of using a Microchip PIC 16F84 18-pin microcontroller is that it is electrically erasable and therefore re-programmable using a low cost PIC programmer. This allows experimentation with different RTTY decode algorithms or variable values.

RTTY assembler code is ready for the Microchip MPLAB assembler, part of the MPLAB development software. This software is freely available from the Microchip web site (www.microchip.com). Type in the assembler code in the same sequence as it is presented and you should end up with a working RTTY decoder program to burn into a 16F84 microcontroller. The assembler code is in upper case and to help understand the assembler code appropriate extracts from the source program are included. Feel free to alter and improve the assembler code.

Define variables routine

The first part of the decoder program defines the PIC registers, the names of the variables used and where the variable value is to be stored in memory. The STATUS register contains various flags including C (carry), Z (zero), RP0 (register banks select). The C flag is set (logic 1) if the result of an arithmetic operation produces a carry-out condition (i.e. most significant bit set). The Z flag is set if the operation result is zero.

Likewise the FLAGS byte contains Boolean flags for LTRS, BUSYFLAG, CONVFLAG, TOPLINE. BINCHAR is the binary representation of the received RTTY character. The config command instructs the assembler on the internal PIC fuse settings (power-up timer enabled, watchdog disabled, crystal oscillator selected).

Start routine

When power is applied to the PIC microcontroller it immediately starts program execution at address zero, this location has a jump instruction to the START routine. ORG assembler command instructs the assembler to generate code from the address given.

```
ORG 0
goto START
```

Interrupt routine

The rising edge of the received audio waveform on PIC port pin RB0 causes an interrupt. When an interrupt occurs the PIC automatically runs interrupt service code located at address 4. This block of code saves the current PIC status and then calls routine INTERRUPT. After returning from executing the INTERRUPT code the registers are restored to their previous values and the RETFIE (return from interrupt) instruction allows the PIC to resume execution as if the interrupt had not occurred.

```
ORG 4     ; interrupt
MOVWF     IRQW
SWAPF     STATUS,W
BCF       STATUS,RP0
MOVWF     IRQS
MOVF      STACK0,W
MOVWF     IRQSTK
CALL      INTERRUPT ;
MOVF      IRQSTK,W
MOVWF     STACK0
SWAPF     IRQS,W
MOVWF     STATUS
SWAPF     IRQW,F
SWAPF     IRQW,W
RETFIE
```

Conversion tables

The character data to convert received RTTY characters into the equivalent ASCII characters for display is stored in look up tables. How this table is derived is quite simple, for example the RTTY 'E' character has a value of 1 (binary 00001), therefore 'E' is located in the 1st position of the table called letters. RTTY character 'A' has a value is 3 (binary 00011) so is located in the 3rd position in the table, and so on for the rest of the RTTY character set. An asterisk character is used where there is a non-print control character defined for that

Fig. 4. Defining the PIC variables used in the RTTY decode program.

```
; Radio Teletype (RTTY) program.
; Written by Roger Thomas.

            list p=16F84
            __config H'3FF9'

; PIC register definitions
RTCC        EQU D'1'     ; timer
STATUS      EQU D'3'     ; status flags
C           EQU D'0'     ; carry
Z           EQU D'2'     ; zero
RP0         EQU D'5'     ; page select
PORTA       EQU D'5'     ; lcd port
RA0         EQU D'0'     ; lcd_RS line
RA1         EQU D'1'     ; lcd_E line
RA2         EQU D'2'     ; lcd_RW line
PORTB       EQU D'6'     ; lcd data port
RB0         EQU D'0'     ; audio input
RB4         EQU D'4'     ; lcd DB4
RB5         EQU D'5'     ; lcd DB5
RB6         EQU D'6'     ; lcd DB6
RB7         EQU D'7'     ; lcd DB6
INTCON      EQU D'11'    ; register
IRQ_RB0     EQU D'1'     ; interrupt flag
IRQ_TIMER   EQU D'2'     ; interrupt timer
OPT         EQU D'1'     ; option register
; program definitions
STACK0      EQU D'12'    ; temp use
STACK1      EQU D'13'    ; temp use
STACK2      EQU D'14'    ; temp use
STACK3      EQU D'15'    ; temp use
STACK4      EQU D'16'    ; temp use
IRQW        EQU D'17'    ; interrupt
IRQS        EQU D'18'    ; interrupt
IRQSTK      EQU D'19'    ; interrupt
RTCCVAL     EQU D'20'    ; timer value
VALRTCC     EQU D'21'    ; timer value
CHAR        EQU D'22'    ; output character
SAVECHAR    EQU D'23'    ; temp save CHAR
TEMP        EQU D'24'    ; store temp value
LCDPOS      EQU D'25'    ; lcd cursor position
MARKCOUNT   EQU D'31'    ; mark frequency count
SPACECOUNT  EQU D'32'    ; space frequency count
BITCOUNT    EQU D'33'    ; which bit of binchar
BINCHAR     EQU D'26'    ; binary RTTY char
CHAR1       EQU D'0'     ; bit 1 RTTY character
CHAR2       EQU D'1'     ; bit 2 RTTY character
CHAR3       EQU D'2'     ; bit 3 RTTY character
CHAR4       EQU D'3'     ; bit 4 RTTY character
CHAR5       EQU D'4'     ; bit 5 RTTY character
FLAGS       EQU D'27'    ; Boolean byte
LTRS        EQU D'0'     ; letter/figure shift
BUSYFLAG    EQU D'1'     ; lcd busy flag
CONVFLAG    EQU D'2'     ; data convert flag
TOPLINE     EQU D'3'     ; top or bottom line
```

Fig. 5. look up tables.

```
; display message
        RETLW D'82'     ; R
        RETLW D'84'     ; T
        RETLW D'84'     ; T
        RETLW D'89'     ; Y
        RETLW D'32'     ; _
        RETLW D'68'     ; D
        RETLW D'69'     ; E
        RETLW D'67'     ; C
        RETLW D'79'     ; O
        RETLW D'68'     ; D
        RETLW D'69'     ; E
        RETLW D'82'     ; R
        RETLW D'32'     ; _
; letters look up table
        RETLW D'37'     ; % (0)
        RETLW D'69'     ; E (1)
        RETLW D'42'     ; * (2)
        RETLW D'65'     ; A (3)
        RETLW D'32'     ; _ (4)
        RETLW D'83'     ; S (5)
        RETLW D'73'     ; I (6)
        RETLW D'85'     ; U (7)
        RETLW D'42'     ; * (8)
        RETLW D'68'     ; D (9)
        RETLW D'82'     ; R (10)
        RETLW D'74'     ; J (11)
        RETLW D'78'     ; N (12)
        RETLW D'70'     ; F (13)
        RETLW D'67'     ; C (14)
        RETLW D'75'     ; K (15)
        RETLW D'84'     ; T (16)
        RETLW D'90'     ; Z (17)
        RETLW D'76'     ; L (18)
        RETLW D'87'     ; W (19)
        RETLW D'72'     ; H (20)
        RETLW D'89'     ; Y (21)
        RETLW D'80'     ; P (22)
        RETLW D'81'     ; Q (23)
        RETLW D'79'     ; O (24)
        RETLW D'66'     ; B (25)
        RETLW D'71'     ; G (26)
        RETLW D'42'     ; * (27)
        RETLW D'77'     ; M (28)
        RETLW D'88'     ; X (29)
        RETLW D'86'     ; V (30)
        RETLW D'42'     ; * (31)
; figures look up table
        RETLW D'37'     ; % (0)
        RETLW D'51'     ; 3 (1)
        RETLW D'42'     ; * (2)
        RETLW D'45'     ; - (3)
        RETLW D'32'     ; _ (4)
        RETLW D'34'     ; " (5)
        RETLW D'56'     ; 8 (6)
        RETLW D'55'     ; 7 (7)
        RETLW D'42'     ; * (8)
        RETLW D'36'     ; $ (9)
        RETLW D'52'     ; 4 (10)
        RETLW D'42'     ; * (11)
        RETLW D'44'     ; , (12)
        RETLW D'33'     ; ! (13)
        RETLW D'58'     ; : (14)
        RETLW D'40'     ; ( (15)
        RETLW D'53'     ; 5 (16)
        RETLW D'43'     ; + (17)
        RETLW D'41'     ; ) (18)
        RETLW D'50'     ; 2 (19)
        RETLW D'35'     ; # (20)
        RETLW D'54'     ; 6 (21)
        RETLW D'48'     ; 0 (22)
        RETLW D'49'     ; 1 (23)
        RETLW D'57'     ; 9 (24)
        RETLW D'63'     ; ? (25)
        RETLW D'38'     ; & (26)
        RETLW D'42'     ; * (27)
        RETLW D'46'     ; . (28)
        RETLW D'47'     ; / (29)
        RETLW D'61'     ; = (30)
        RETLW D'42'     ; * (31)
; end of tables
```

particular position. For example, RTTY character 2 (binary 00010) is a line feed control character. There is a similar table for numbers and punctuation.

These look up tables (including the RTTY LCD message) are stored sequentially in memory in ascending order located after the interrupt handler routine.

Audio conversion

To calculate the specific mark and space audio frequencies that the RTTY program has to respond to the following formula is used, assuming a 4MHz clock crystal. The actual timer frequency used is the 4MHz clock divided internally in the microcontroller by four.

$$\frac{\text{clock frequency} / 4}{\text{frequency Hz}} = \frac{4{,}000{,}000/4}{\text{space Hz}} = \frac{1{,}000{,}000}{1275} = 784.3$$

$$\frac{\text{clock frequency} / 4}{\text{frequency Hz}} = \frac{4{,}000{,}000/4}{\text{mark Hz}} = \frac{1{,}000{,}000}{1445} = 692$$

These numbers cannot be represented by the RTCC (Real Time Clock Counter) timer which is 8 bit (0 to 255 range), thus the clock used by the RTCC has to be divided by 4 using the internal prescaler.

$$\text{space} = \frac{1{,}000{,}000}{1275} = \frac{784}{4} = 196$$

$$\text{mark} = \frac{1{,}000{,}000}{1445} = \frac{692}{4} = 173$$

Fig. 6. valRTCC centre values

space	mark	shift
1275Hz = 196	1445Hz = 173	170Hz
1275Hz = 196	1700Hz = 147	425Hz
1275Hz = 196	2125Hz = 118	825Hz

Start routine

The START routine is always called whenever the PIC is reset. START routine calls INITVAR, INITPORT, INITLCD, and DISPLAY. After this the prescaler ratio is set (using bits PSx defined in the OPTION register). The PSA bit is set to 0, which assigns the prescaler to the timer rather than the watchdog timer. RB0 interrupt is selected and enabled in the INTCON register.

```
START   CALL    INITVAR ; initialise variables
        CALL    INITPORT ; initialise PIC ports
        CALL    INITLCD ; initialise display
        CALL    DISPLAY ; display RTTY message
        BSF     STATUS,RP0
        BCF     OPT,5    ; PIC clock as source
; prescaler (4000000 / 4) by 4
        BSF     OPT,0    ; PS0
        BCF     OPT,1    ; PS1
        BCF     OPT,2    ; PS2
        BCF     OPT,3    ; PSA
; use RB0 as interrupt source
        BCF     STATUS,RP0
        BSF     INTCON,4 ; IRQ RB0 enable
        BSF     INTCON,7 ; interrupt enable
```

Loop routine

After initialising various options within the PIC microcontroller the program sits in the loop checking the CONVFLAG Boolean flag. This flag is set (true) in the INTERRUPT routine to indicate whenever new data is available and this flag is tested using the BTFSS instruction (Bit Test File, Skip if Set). If CONVFLAG is false then the next instruction GOTO LOOP is executed. If the result of the BTFSS is true the GOTO LOOP instruction is ignored and the CALL CONVERT is executed. File is Microchip terminology for what everyone else calls a register.

```
LOOP    BTFSS   FLAGS,CONVFLAG
        GOTO    LOOP
; if convflag = true then
        CALL    CONVERT
        GOTO    LOOP
```

Initialise routine

INITVAR (initialise variables) routine sets various variables to zero using CLRF (Clear Register File) single instruction.

INITPORT (initialise port) routine configures the various port pins that are attached to the LCD display as outputs using the BCF (Bit Clear File). Port pin RBO is set as an input using BSF (Bit Set File) instruction; this is the PIC pin that the RTTY audio is connected to.

```
INITVAR         CLRF    MARKCOUNT ; = 0
        CLRF    SPACECOUNT ; = 0
        CLRF    LCDPOS ; = 0
        CLRF    BITCOUNT  ; = 0
        CLRF    BINCHAR ; = 00000
        CLRF    FLAGS ; bits = false
; topline = true
        BSF     FLAGS,TOPLINE
; ltrs = true
        BSF     FLAGS,LTRS
        RETURN

INITPORT        BSF     STATUS,RP0 ; page 1
        BCF     PORTA,RA0           ; output
        BCF     PORTA,RA1           ; output
        BCF     PORTA,RA2           ; output
        BCF     PORTB,RB4           ; output
        BCF     PORTB,RB5           ; output
        BCF     PORTB,RB6           ; output
        BCF     PORTB,RB7           ; output
        BSF     PORTB,RB0           ; input
        BCF     STATUS,RP0          ; page 0
        RETURN
```

Read timer interrupt routine

In the following interrupt routine, the 8-bit RTCC counter value is assigned to RTCCVAL variable. The timer overflow flag is set if the counter has reached 255 (maximum byte value) and has started counting again. The status of this flag is checked and if the timer overflow flag is true then the program will ignore the timer value as it is invalid.

The RTCC count is then cleared and starts to automatically count up from zero and the flags indicating an interrupt condition are cleared. After this call the PIC re-loads the previously saved information and resumes processing from where it was before the interrupt had occurred.

```
interrupt:
if irq_timer = false then
begin
        RTCCval = rtcc    ;read 8 bit timer value
        convflag = true   ; set data ready flag
end
clr(rtcc)       ; zero 8 bit timer
irq_RB0 = false ; clear interrupt flag
irq_timer = false       ; clear interrupt flag


INTERRUPT
        BTFSC    INTCON,IRQ_TIMER
        GOTO     INVALID  ; timer overflow
; RTCCval = rtcc (read 8 bit timer value)
        MOVF     RTCC,W
        MOVWF    RTCCVAL
; convflag = true set data ready flag
        BSF      FLAGS,CONVFLAG
INVALID          CLRF     RTCC     ; zero 8 bit timer
; irq_RB0 = false (clear interrupt flag)
        BCF      INTCON,IRQ_RB0
        BCF      INTCON,IRQ_TIMER
        RETURN
```

Convert RTTY mark audio

Within the routine, CONVERT the MarkCount and SpaceCount variables translates a sequence of mark or space frequency into either a 1 or 0 by counting the number of consecutive pulses received.

With reference to the line if (valRTCC >= 161) and (valRTCC <= 185), the two numbers set the mark frequency (1445Hz) capture range as 1553Hz to 1352Hz. Any number received within this range will be treated as a mark frequency and will increment the MarkCount variable accordingly. Variable bit count is used to keep track of which bit within the BINCHAR variable is to be used. After receiving a predetermined number of mark frequencies (26) a '1' is added to the BINCHAR variable by making the relevant charX bit within BINCHAR to '1'. BINCHAR (binary character) becomes the binary representation of the received RTTY character.

The start bit of a RTTY character is always a space frequency, so if a mark frequency is detected as the first bit received this will be ignored and the bitcount is set back to zero. This helps prevent random noise generating random text. A RTTY station will send a continuous mark tone if there is no text ready to transmit.

```
; Mark - 1445Hz
if (valRTCC >= 161) and (valRTCC <= 185) then
begin
        inc(MarkCount)    ; MarkCount = MarkCount+1
        if MarkCount >= 26 then
        begin
                clr(SpaceCount)  ; SpaceCount = 0
                clr(MarkCount)   ; MarkCount = 0
                 inc(bitcount)      ; bitcount = bitcount+1

                select bitcount
                  case 1 : clr(bitcount); waiting for space
                  case 2 : char1 = 1    ; set bit to 1
                  case 3 : char2 = 1    ; set bit to 1
                  case 4 : char3 = 1    ; set bit to 1
                  case 5 : char4 = 1    ; set bit to 1
                  case 6 : char5 = 1    ; set bit to 1
                        Text
                end select
        end if
end if

; clear data ready flag
CONVERT         BCF     FLAGS,CONVFLAG
; valRTCC = RTCCval
        MOVF    RTCCVAL,W
        MOVWF   VALRTCC
; Mark - 1445Hz
; if valRTCC >= 161 and <= 185 then
        MOVF    VALRTCC,W
        MOVWF   STACK0
        MOVLW   D'161'
        SUBWF   STACK0,W
        CLRW
        BTFSC   STATUS,C
        ADDLW   D'255'
        MOVWF   STACK4
        MOVF    VALRTCC,W
        SUBLW   D'185'
        CLRW
        BTFSC   STATUS,C
        ADDLW   D'255'
        ANDWF   STACK4,W
        BTFSC   STATUS,Z
        GOTO    SPACEF
; MarkCount = MarkCount+1
        INCF    MARKCOUNT,F
; if MarkCount >= 26 then
        MOVF    MARKCOUNT,W
        MOVWF   STACK0
        MOVLW   D'26'
        SUBWF   STACK0,W
        BTFSS   STATUS,C
        GOTO    SPACEF
```

```
        CLRF     SPACECOUNT        ; = 0
        CLRF     MARKCOUNT         ; = 0
        INCF     BITCOUNT,F        ; +1
; bit 1 waiting for space
BIT1    MOVF     BITCOUNT,W
        SUBLW    D'1'
        BTFSS    STATUS,Z
        GOTO     BIT2
        CLRF     BITCOUNT
        GOTO     ALLDONE
BIT2    MOVF     BITCOUNT,W
        SUBLW    D'2'
        BTFSS    STATUS,Z
        GOTO     BIT3
        BSF      BINCHAR,CHAR1     ; set bit
BIT3    MOVF     BITCOUNT,W
        SUBLW    D'3'
        BTFSS    STATUS,Z
        GOTO     BIT4
        BSF      BINCHAR,CHAR2     ; set bit
        GOTO     ALLDONE
BIT4    MOVF     BITCOUNT,W
        SUBLW    D'4'
        BTFSS    STATUS,Z
        GOTO     BIT5
        BSF      BINCHAR,CHAR3     ; set bit
        GOTO     ALLDONE
BIT5    MOVF     BITCOUNT,W
        SUBLW    D'5'
        BTFSS    STATUS,Z
        GOTO     BIT6
        BSF      BINCHAR,CHAR4     ; set bit
        GOTO     ALLDONE
BIT6    MOVF     BITCOUNT,W
        SUBLW    D'6'
        BTFSS    STATUS,Z
        GOTO     ALLDONE
        BSF      BINCHAR,CHAR5     ; set bit
        CALL     TEXT
```

Convert RTTY space audio

Using valRTCC numbers of 181 to 212 gives a frequency capture range of 1381Hz to 1179Hz and any number received within this range will increment the SpaceCount variable. The relevant BINCHAR bit variable is already '0' so the space routine does not need to change BINCHAR but still needs to increment variable bitcount to point to the next bit.

```
; Space - 1275Hz
if (valRTCC >= 181) and (valRTCC <= 212) then
begin
    inc(SpaceCount) ; SpaceCount = SpaceCount +1
    if SpaceCount >= 24 then
    begin
       clr(MarkCount)    ; MarkCount = 0
       clr(SpaceCount)   ; SpaceCount = 0
       inc(bitcount)     ; bitcount = bitcount+1
       if bitcount = 6 then
       begin
           Text
       end
    end
end

; Space - 1275Hz
; if valRTCC >= 181 and <= 212 then
SPACEF MOVF     VALRTCC,W
       MOVWF    STACK0
       MOVLW    D'181'
       SUBWF    STACK0,W
       CLRW
       BTFSC    STATUS,C
       ADDLW    D'255'
       MOVWF    STACK4
       MOVF     VALRTCC,W
       SUBLW    D'212'
       CLRW
       BTFSC    STATUS,C
       ADDLW    D'255'
       ANDWF    STACK4,W
       BTFSC    STATUS,Z
       GOTO     ALLDONE
; SpaceCount = SpaceCount +1
       INCF     SPACECOUNT,F
; if SpaceCount >= 24 then
       MOVF     SPACECOUNT,W
       MOVWF    STACK0
       MOVLW    D'24'
       SUBWF    STACK0,W
       BTFSS    STATUS,C
       GOTO     ALLDONE
       CLRF     MARKCOUNT ; = 0
       CLRF     SPACECOUNT ; = 0
; bitcount = bitcount+1
       INCF     BITCOUNT,F
; if bitcount = 6 then
       MOVF     BITCOUNT,W
       SUBLW    D'6'
       BTFSS    STATUS,Z
       GOTO     ALLDONE
       CALL     TEXT
ALLDONE         RETURN
```

Text output routine

After receiving five bits (BITCOUNT = 6) the Text routine is called (stop bits are ignored). Within the Text routine the value of BINCHAR (binary char) is checked for a control character such as carriage return, line feed or letter/figure shift.

If a space character is received (BINCHAR value equals 4), this forces the program to use the letters table then the space character is sent to the display. As the display is only two lines, any carriage returns or line feeds received result in the display cursor being moved to the beginning of the top line but the existing text is not erased.

If the received character (char) is not a control character then it is converted into an ASCII character based on a look up table and sent to the display. For example, if the binary sequence of the BINCHAR variable is 01010 then the decimal equivalent is (msb first) 0+8+0+2+0 = 10. The look up (read) routine is used to access the tenth item in the letters table and returns the character 'R' in the char variable. The appropriate table (letters or numbers) is selected by the Boolean value of the LTRS variable.

Char variable is used in the TEXTLCD routine that handles sending this value to the display. The TEXTLCD routine also keeps track of where the cursor is (LCDPOS) and will move from the end of the top line to the first position on the bottom line when appropriate (TOPLINE flag).

If the value of char is 255 then we have received a non-print character and the second half of the routine is not called.

```
Text:
clr(bitcount)
char = '?'
select binchar
   case b'00100' : ltrs = true  ;space forces letter shift
   case b'01000' : clr(lcdpos)  ;carriage return
                   char = b'10000000' ; cursor to top line
                   CommandLCD
                   topline = true     ; lcd top line
                   char = 255
   case b'00010' : clr(lcdpos)        ; line feed
                   char = b'10000000' ; cursor to top line
```

```
                CommandLCD
                topline = true    ; lcd top line
                char = 255
        case b'11011' :  ltrs = false     ; figure shift
                char = 255
        case b'11111' :  ltrs = true      ; letters shift
                char = 255
end select

if char <> 255 then ; 255 = non-print character
begin
        if ltrs = true then
        begin
            read(letters,binchar,char)
            TextLCD
        end
        else
        begin
            read(numbers,binchar,char)
            TextLCD
        end
end
clr(binchar)    ; = b'00000'


TEXT    CLRF    BITCOUNT ; = 0
        MOVLW   D'63'
        MOVWF   CHAR     ; char = '?'
        MOVF    BINCHAR,W
        SUBLW   D'4'     ; space ?
        BTFSS   STATUS,Z
        GOTO    CR
        BSF     FLAGS,LTRS
        GOTO    TEXT1
; carriage return ? (4)
CR      MOVF    BINCHAR,W
        SUBLW   D'8'
        BTFSS   STATUS,Z
        GOTO    LF
        CLRF    LCDPOS
; char = b'10000000'
; cursor to top line
        MOVLW   D'128'
        MOVWF   CHAR
        CALL    COMMANDLCD
; topline = true
        BSF     FLAGS,TOPLINE
        MOVLW   D'255'
        MOVWF   CHAR
        GOTO    TEXT1
; line feed ? (2)
LF      MOVF    BINCHAR,W
        SUBLW   D'2'
        BTFSS   STATUS,Z
        GOTO    FS
        CLRF    LCDPOS
; char = b'10000000'
; cursor to top line
        MOVLW   D'128'
        MOVWF   CHAR
        CALL    COMMANDLCD
; topline = true lcd top line
        BSF     FLAGS,TOPLINE
        MOVLW   D'255'
        MOVWF   CHAR
        GOTO    TEXT1
; figure shift ? (27)
FS      MOVF    BINCHAR,W
        SUBLW   D'27'
BTFSS   STATUS,Z
        GOTO    LS
```

```
        BCF     FLAGS,LTRS
        MOVLW   D'255'
        MOVWF   CHAR
        GOTO    TEXT1
;letter shift ? (31)
LS      MOVF    BINCHAR,W
        SUBLW   D'31'
        BTFSS   STATUS,Z
        GOTO    TEXT1
        BSF     FLAGS,LTRS
        MOVLW   D'255'
        MOVWF   CHAR

; if char <> 255 then
TEXT1   MOVF    CHAR,W
        MOVWF   STACK0
        MOVLW   D'255'
        SUBWF   STACK0,W
        BTFSC   STATUS,C
        GOTO    ENDTEXT
        BTFSS   FLAGS,LTRS
        GOTO    NUMBER
; if ltrs = true then
; char = read(letters,binchar)
        MOVLW   D'31'
        MOVWF   STACK0
        MOVLW   D'0'
        MOVWF   STACK1
        MOVF    BINCHAR,W
        MOVWF   STACK2
        CLRF    STACK3
        CALL    READ
        MOVWF   CHAR
        CALL    TEXTLCD
        GOTO    ENDTEXT
; if ltrs = false then
; char = read(numbers,binchar)
NUMBER MOVLW    D'63'
        MOVWF   STACK0
        MOVLW   D'0'
        MOVWF   STACK1
        MOVF    BINCHAR,W
        MOVWF   STACK2
        CLRF    STACK3
        CALL    READ
        MOVWF   CHAR
        CALL    TEXTLCD
ENDTEXT CLRF    BINCHAR  ; = b'00000'
        RETURN
```

RTTY element timing

For 45 baud RTTY each element (bit) of the character is 22ms long, for 50 baud each element is 20ms long.

Fig. 7. Integer values for MarkCount and SpaceCount.

45 baud	1445 * 22ms = 31 (mark)
	1275 * 22ms = 28 (space)
50 baud	1445 * 20ms = 28 (mark)
	1275 * 20ms = 25 (space)
75 baud	1445 * 13ms = 18 (mark)
	1275 * 13ms = 16 (space)

A compromise has to be reached between the theoretical and actual number chosen for the mark and space comparison count. Too small a number and one bit may be interpreted as two consecutive bits or two consecutive bits misread as three bits. Too large and a poor quality RTTY signal may never reach the required number. If the parameters are too exact then the PIC program will only accept RTTY that is 'perfect'. Ideally we want the software to respond to both 45 and 50 baud. With all these numbers there will be small variations due to interrupt latency.

Fig. 8. Summary of LCD commands.

instruction	RS	RW	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	instruction description
clear display	0	0	0	0	0	0	0	0	0	1	clears display and cursor to home position
cursor home	0	0	0	0	0	0	0	0	1	X	returns cursor to home position
entry mode set	0	0	0	0	0	0	0	1	I	S	I - sets cursor move direction (0 = decrement, 1= increment) S - shift display
display control	0	0	0	0	0	0	1	D	C	B	D - on/off of display C - cursor on/off B - blink cursor character
cursor/display shift	0	0	0	0	0	1	S	D	X	X	S - sets cursor move or display shift D - shift direction (1=right or 0=left)
function set	0	0	0	0	1	D	N	F	X	X	D - interface data length (4 or 8 bit) N - number of display line (1 or 2 lines) F - character font (0=5x10 or 1=5x7)
read busy flag	0	1	B	x	x	x	x	x	x	x	B - busy flag 1 = busy 0 = not busy
move cursor	0	0	1	a	a	a	a	a	a	a	move cursor to address aaaaaaa a = 0 line 1, position 1 a = 64 line 2, position 1
write character	1	0	d	d	d	d	d	d	d	d	write character dddddddd to display at current cursor position

To change the frequency range the valRTCC values need to be altered within the assembler program. Selecting too narrow a frequency range may make tuning difficult and not all amateur transmissions have exactly the right shift. Frequency drift within the receiver itself may need to be taken into consideration. Making the frequency range wider makes tuning easier and increases the chance of receiving less than perfect RTTY, however noise and co-channel interference could introduce errors.

RYRYRY

As the letter R is alternating between space and mark (01010) and the letter Y alternates between mark and space (10101) these two characters are sometimes used alternately (RYRY) when calling CQ. This distinctive pattern helps receiving stations to tune to the transmissions. Numbers 4 and 6 will appear if the figure table is being used.

LCD display

A low cost 16 character, two-line LCD is used to display the received RTTY text. The vast majority of these are based around the Hitachi HD44780 (or compatible) display controller. The display is initialised by calling routine InitLCD, the device is set for 4 bit data transfer, 2 display lines, 5x7 font, cursor on and character blink off.

Using a LCD connected to a PIC is a low cost and convenient method of displaying text, both the display and PIC circuit will run off a +5 volt regulated supply.

Although the interface to the LCD is 4 bits it may seem odd for the first three instructions sent (routine InitLCD) to set the data bus interface to 8 bits. The reason for this is that with a four bit interface there is no mechanism to tell the LCD which four bits is being sent (i.e. upper or lower nibble). If the LCD misses a nibble it will be out of sync for all the following data. During initialisation this will cause the LCD to be set in the wrong mode. Sending the 8 bit mode command (the four unconnected bits DB0 to DB3 will be correctly read) makes sure that everything is working correctly before the transfer mode is switched to four bits.

Fig. 9. LCD address of each display character position.

position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
line 1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
line 2	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79

Fig. 10. Initialise LCD.

```
INITLCD
; char = b'00110000' 8 bit mode
        MOVLW    D'48'
        MOVWF    CHAR
        CALL     INILCD
; char = b'00110000' 8 bit mode
        MOVLW    D'48'
        MOVWF    CHAR
        CALL     INILCD
; char = b'00110000' 8 bit mode
        MOVLW    D'48'
        MOVWF    CHAR
        CALL     INILCD
; char = b'00101000'
; 4 bit, 2 lines, 5x7 font
        MOVLW    D'40'
        MOVWF    CHAR
        CALL     COMMANDLCD
; char = b'00011000'
; cursor move, right shift
        MOVLW    D'24'
        MOVWF    CHAR
        CALL     COMMANDLCD
; char = b'00001110'
; display+cursor on,blink off
        MOVLW    D'14'
        MOVWF    CHAR
        CALL     COMMANDLCD
; char = b'00000100' entry mode
        MOVLW    D'4'
        MOVWF    CHAR
        CALL     COMMANDLCD
; char = b'00000001' clear display
        MOVLW    D'1'
        MOVWF    CHAR
        CALL     COMMANDLCD
        RETURN


COMMANDLCD
        CALL     WAIT      ; is lcd busy ?
        BCF      PORTA,RA2
        BCF      PORTA,RA0
```

```
; send routine to output 4 bits
        CALL     SEND
; swap over lower 4 bits
        SWAPF    CHAR,F
        CALL     SEND
        RETURN

INILCD CALL      WAIT
        BCF      PORTA,RA2
        BCF      PORTA,RA0
        CALL     SEND
        RETURN
```

Displaying RTTY text

The text and data is transferred to the display four bits at a time (routine send). The variable LCDPOS (LCD cursor position) is to make sure that we have not passed the end of the display line. If you are using a LCD that can display more than 16 characters then change this number. If the cursor is at the end of the line then the output character is stored and the Boolean flag is checked to see if the display is using the top or bottom display line. The appropriate command is then sent to the LCD to use the other display line and the cursor set to the first position before restoring the character and sending that to the LCD.

The higher four bits are sent first then the four lower bits. The swap command is used to exchange the lower and upper 4 bits of the byte, hence the output routine (SEND) is called twice.

Fig. 11. LCD text output routines.

```
TextLCD:
if lcdpos > 15 then ; end of lcd line ?
begin
     clr(lcdpos)    ; position 0
     savechar = char; temp save char
     if topline = false then
     begin
          char = b'10000000'     ; cursor to top line
          CommandLCD
          topline = true
     end
     else
     begin
          char = b'10000000'+64 ;cursor to bottom line
          CommandLCD
          topline = false
     end
     char = savechar  ; restore original value
end
call wait                 ; is lcd busy ?
RA2 = 0                   ; 0 - writing to lcd
RA0 = 1                   ; 1 - data register
call send                 ; output upper 4 bits
swap(char)            ; swap lower/upper 4 bits
call send                 ; output upper 4 bits
inc(lcdpos)           ; next lcd position


TEXTLCD  MOVF        LCDPOS,W
         SUBLW       D'15'        ; LCD
         BTFSC       STATUS,C
         GOTO        LINE
; if lcdpos > 15 then
         CLRF             LCDPOS  ; position 0
;        savechar = char
         MOVF             CHAR,W
         MOVWF            SAVECHAR
; if topline = false then
         BTFSC            FLAGS,TOPLINE
         GOTO             BOTTM
```

```
; char = b'10000000' cursor to top line
        MOVLW     D'128'
        MOVWF     CHAR
        CALL      COMMANDLCD
        BSF       FLAGS,TOPLINE
        GOTO      REST
; char = b'10000000'+64
; cursor to bottom line
BOTTM   MOVLW     D'192'
        MOVWF     CHAR
        CALL      COMMANDLCD
        BCF       FLAGS,TOPLINE
; char = savechar
; restore original value
REST    MOVF      SAVECHAR,W
        MOVWF     CHAR
; is lcd busy ?
LINE    CALL      WAIT
        BCF       PORTA,RA2
        BSF       PORTA,RA0
; send  output upper 4 bits
        CALL      SEND
; swap lower/upper 4 bits
        SWAPF     CHAR,F
        CALL      SEND
; next lcd position
        INCF      LCDPOS,F
        RETURN


SEND
; RB4 = char AND b'00010000'
        MOVF      CHAR,W
        ANDLW     D'16'
        BTFSS     STATUS,Z
        BSF       PORTB,RB4
        BTFSC     STATUS,Z
        BCF       PORTB,RB4
; RB5 = char AND b'00100000'
        MOVF      CHAR,W
        ANDLW     D'32'
        BTFSS     STATUS,Z
        BSF       PORTB,RB5
        BTFSC     STATUS,Z
        BCF       PORTB,RB5
; RB6 = char AND b'01000000'
        MOVF      CHAR,W
        ANDLW     D'64'
        BTFSS     STATUS,Z
        BSF       PORTB,RB6
        BTFSC     STATUS,Z
        BCF       PORTB,RB6
; RB7 = char AND b'10000000'
        MOVF      CHAR,W
        ANDLW     D'128'
        BTFSS     STATUS,Z
        BSF       PORTB,RB7
        BTFSC     STATUS,Z
        BCF       PORTB,RB7
; RA1 = 1 (enable high to low)
        BSF       PORTA,RA1
; RA1 = 0 (data valid)
        BCF       PORTA,RA1
        RETURN
```

Port A (bits 0 to 2) is used to provide the LCD control lines and port B (bits 4 to 7) is used as the four bit data bus. The Enable control line (RA1) is used to inform the display that data is available by taking the line high then low.

Fig. 12. Summary of LCD control lines.

PIC	name	function	
RA2	lcd_rw	read/write	0 - write, 1 - read
RA1	lcd_e	enable	1/0 data available
RA0	lcd_rs	register select	0 instruction register
			1 display register

These LCD displays are slow in comparison to the operation of a PIC micro-controller and require time to complete commands. These range from 40ms to 60ms when sending data and up to 2ms for clearing the display. Worst case delays have to be assumed to ensure that the command has been completed, which may make the program wait unnecessarily before communicating with the display.

By polling the display's busy flag to see if it can accept data means that the PIC program can send data to the display without using software time delays. To enable the PIC to send text to the display as fast as possible the LCD's internal busy flag is read in routine wait. This requires the port to switch from output to input. Busy flag is contained in the status byte as the most significant bit (the rest of the status information is ignored).

Fig. 13. LCD wait routine.

```
wait:
RA2 = 1          ; 1 - reading from lcd
RA0 = 0          ; 0 - instruction register
input(RB4)       ; make port pin input
input(RB5)       ; make port pin input
input(RB6)       ; make port pin input
input(RB7)       ; make port pin input
busyflag = true          ; is lcd busy ?
while busyflag = true    ; 1 = busy 0 = ready
    RA1 = 1                          ; read data high to low
    busyflag = RB7       ; read msb bit
    RA1 = 0      ; receive upper 4 bits first
    RA1 = 1      ; not interested in lower 4
    RA1 = 0      ; ignore rest of status byte
loop    ; if busy keep in the loop
output(RB4)      ; make port pin output
output(RB5)      ; make port pin output
output(RB6)      ; make port pin output
output(RB7)      ; make port pin output
WAIT    BSF      PORTA,RA2          ; reading lcd
        BCF      PORTA,RA0          ; instruction register
        BSF      STATUS,RP0
        BSF      PORTB,RB4          ; pin input
        BSF      PORTB,RB5          ; pin input
        BSF      PORTB,RB6          ; pin input
        BSF      PORTB,RB7          ; pin input
        BCF      STATUS,RP0
        BSF      FLAGS,BUSYFLAG
; while busyflag = true (1 = busy 0 = ready)
BUSY    BTFSS    FLAGS,BUSYFLAG
        GOTO     READY
; if busy keep in loop
        BSF      PORTA,RA1
; busyflag = RB7
        BTFSC    PORTB,RB7
        BSF      FLAGS,BUSYFLAG
        BTFSS    PORTB,RB7
        BCF      FLAGS,BUSYFLAG
        BCF      PORTA,RA1
        BSF      PORTA,RA1
        BCF      PORTA,RA1
        GOTO     BUSY
READY   BSF      STATUS,RP0
        BCF      PORTB,RB4          ; pin output
        BCF      PORTB,RB5          ; pin output
        BCF      PORTB,RB6          ; pin output
        BCF      PORTB,RB7          ; pin output
        BCF      STATUS,RP0
        RETURN
```

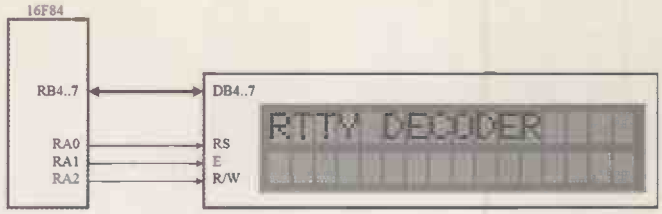


Fig. 14. LCD wiring diagram.

Fig. 15. PIC connection list.

RA0	17	-	output to lcd RS line
RA1	18	-	output to lcd E line
RA2	1	-	output to lcd R/W line
RB4	10	-	data bus to lcd DB4
RB5	11	-	data bus to lcd DB5
RB6	12	-	data bus to lcd DB6
RB7	13	-	data bus to lcd DB7
Vdd	14	-	power supply +5v
Vss	5	-	power supply 0v
mclr	4	-	power supply +5v
RB0	6	-	audio input
osc2	15	-	4 MHz crystal
osc1	16	-	4 MHz crystal

Fig, 16. LCD pin description.

Vss	1	-	ground
VDD	2	-	+5v
VO	3	-	contrast voltage
RS	4	-	register select line
R/W	5	-	read/write line
E	6	-	enable line
DB4	11	-	data bus 4
DB5	12	-	data bus 5
DB6	13	-	data bus 6
DB7	14	-	data bus 7
Vled	15	-	back lighting (optional)
Vled	16	-	back lighting (optional)

Fig. 17. Component list.

R1	-	120kW
R2	-	1kW
R3	-	47kW
VR1	-	47kW linear (audio)
VR2	-	47kW linear (lcd contrast)
C1, 4	-	100nF ceramic
C2, 3	-	10uF electrolytic
C5, 6	-	33pF ceramic
TR1	-	BC549 or similar
IC1	-	PIC 16F84
IC2	-	74LS14 (hex buffer)
X1	-	4MHz crystal
LCD	-	16 by 2 line display

Circuit description

The circuit can be built using strip board with the majority of connections between the display and the PIC. LCD displays either have a single line of 14 pin holes or a double row of seven pins holes. If the display has a back lighting option then there will be 16 holes.

The LCD display may need a potentiometer (20-50 kW) to set the contrast voltage. This potentiometer should be connected between the positive supply rail and ground, connect the wiper to the LCD contrast pin (usually pin 3). If after reset no message is visible then this setting may need to be altered. Once this potentiometer is set for the best viewing angle it should not need to be altered again. For simplicity this contrast line can be connected direct to 0v line but the viewing angle may not be optimal.

The circuit should be connected to a +5 volt regulated supply. Display and PIC circuit will consume around 8-10mA but this rises considerably if display back lighting is used. The amount of current depends on the type of back lighting, the display that I have (manufactured by Anders) has two side type LEDS and consumes over 50mA when using the back lighting option.

Display routine

When power is first applied to the circuit, the PIC program should display 'RTTY DECODER' message, demonstrating that the program and display has been initialised correctly. The READ routine gets the appropriate character from the look up table.

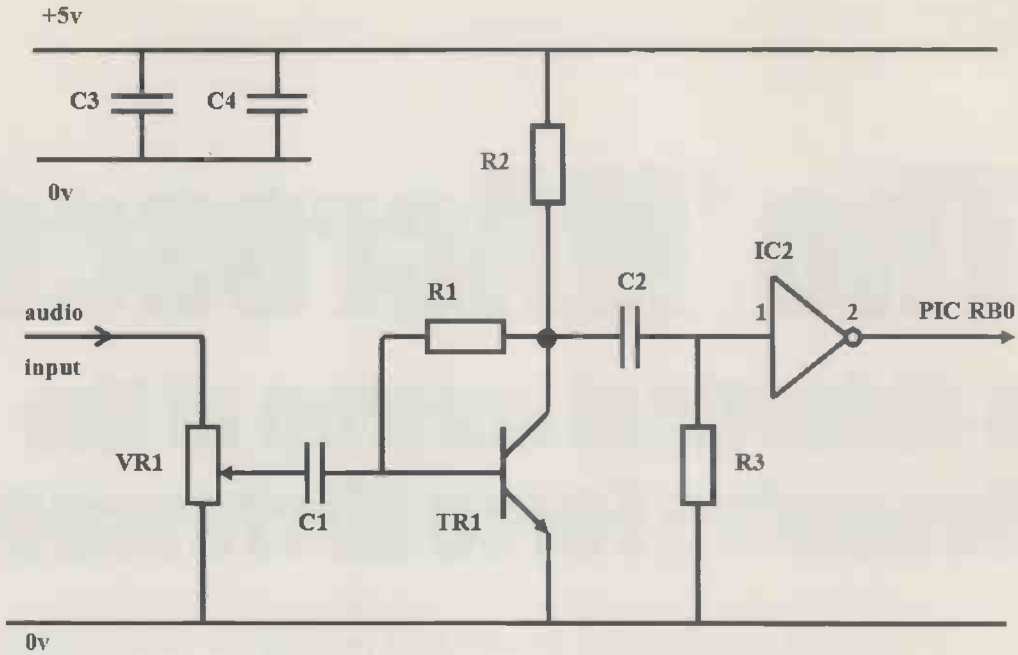


Fig. 18. interface circuit.

```
display:
temp = 0
while temp <= 11 ; 11 characters in text
     read[ready,temp,char]
     TextLCD      ; char = ready[temp]
     inc(temp)    ; next character
loop
```

```
DISPLAY CLRF    TEMP ; =0
; 11 characters in text
DISP1   MOVF    TEMP,W
        SUBLW   D'11'
        BTFSS   STATUS,C
        GOTO    DONE
; char = read(ready,temp)
        MOVLW   D'18'
        MOVWF   STACK0
        MOVLW   D'0'
        MOVWF   STACK1
        MOVF    TEMP,W
        MOVWF   STACK2
        CLRF    STACK3
        CALL    READ
        MOVWF   CHAR
        CALL    TEXTLCD
; next character
        INCF    TEMP,F
        GOTO    DISP1
DONE RETURN

; Read from table
READ    MOVF    STACK0,W
        ADDWF   STACK2,f
        BTFSC   3,2
        INCF    STACK1,f
        MOVF    STACK1,W
        ADDWF   STACK3,W
        MOVWF   D'10' ; PCLATH
        MOVF    STACK2,W
        MOVWF   D'2'  ; PCL
        END
```

Interface circuit

The transistor interface circuit is designed to be connected to the loudspeaker or headphones output of the receiver. Connection to the receiver is by screened audio cable, soldered either side of VR1 potentiometer. Set the potentiometer and volume control as appropriate when the radio is receiving RTTY for correct reception and comfortable listening level.

The transistor circuit changes the shape of the audio sine wave into a square wave. Using the 74LS14 buffer guarantees a constant amplitude TTL signal so that the audio edge properly triggers the PIC interrupt. The 74LS14 buffer has a Schmitt trigger type input which ensures a clean output signal and makes the interface less sensitive to noise. I used a BC549 npn transistor (plastic version of BC109) in the prototype but any general purpose npn transistor will do. Ideally, the interface circuit should be housed in a metal box to prevent any radio signals generated by the PIC from being picked up by the receiver. Take care with the input level to prevent excessive signal input. Although some clipping of the audio signal does not affect the operation of the PIC as it is triggered on the waveform edge.

To check the operation of the circuit in the absence of a RTTY signal, find a clear steady tone and tune very slowly until a row of % characters appear on the display (BINCHAR value of 0 being received). Under normal operations this display would signify that the tuning is close but incorrect. The frequency is being processed as a space frequency but a steady tone being transmitted by a RTTY station should be a mark frequency. The stronger and clearer the radio signal is the more RTTY will be correctly decoded.

Despite more 'modern' forms of data communications, there are still many RTTY signals to be heard on the amateur bands. A few radio amateurs continue to use mechanical printers but the majority use a computer and software. Indeed it is because RTTY signals can be produced and decoded entirely by computer software, and ease of operation, which has contributed to its continued use. ■

The 'MAcroscope': a didactical version of the Scanning Force Microscope

A homemade device that mimics, at macroscopic level, the behaviour of an SFM (Scanning Force Microscope) that may be used for didactic purposes aimed at clarifying genesis and meaning of electronic micrographs. Giacomo Torzo, Barbara Pecori, Pietro Scatturin and Giorgio Delfitto[1] elucidate

Our world is full of images. Some of them, like the image of a coin, are part of a general background knowledge and, appearing 'natural', do not raise any curiosity about the mechanisms generating the image. But if we try to find out the value of a coin inside our pocket by hand inspection only, the process involved in our fingers collecting data and our brain transforming data into a 'coin image' is different from the usual way of transforming the eye's signals into images. It is more similar to the process used in modern scanning force microscopy (SFM).

These considerations brought us to design a device that could be used, even by students with a poor physics background, to help understanding the basic processes through which images are normally built from electric signals acquired by sensors. The basic idea is to use a device working at macroscopic level with techniques similar to those used investigating the microscopic world.

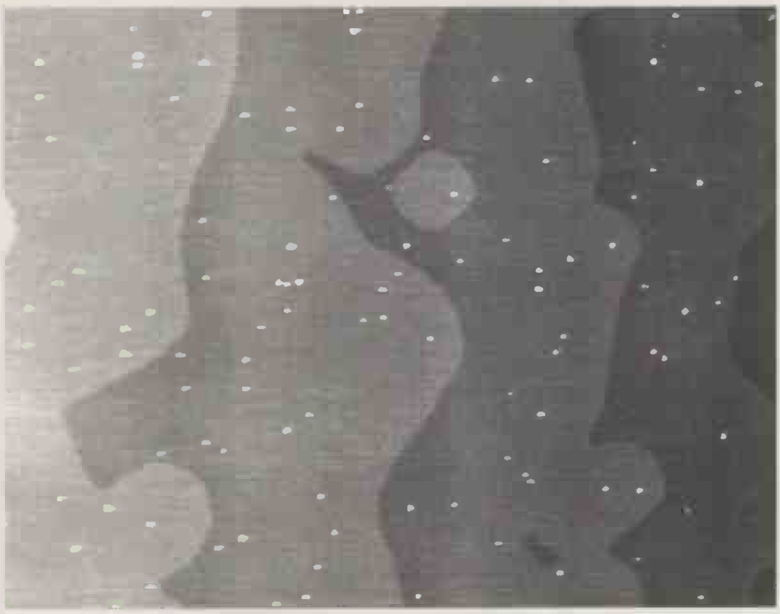


Fig. 1. SFM image of InAs nanoislands on GaAs substrate (3x3mm)

How are topographic images produced?

Electronic images may be of a different type. The simplest is the 'bit-mapped' one, i.e. *matrix of dots* of different colours that may be printed or displayed on a computer screen. Each pixel is a numeric value in the matrix stored in the computer memory.

Topographic images are special images, that give a quantitative representation of the surface of an object, where the colour of each pixel 'measures' the distance z from a geometric plane parallel to the average surface of the object ($z=z_0$).

If we pick up only a row of the matrix, we obtain a vertical cross-section of the topographic image.

By plotting this set of numbers versus their position along x, with segments joining the nearby dots, we get an x-line profile. Putting in the same plot all the x-line profiles corresponding to the various y positions (each one shifted upward of the same quantity Δz) we obtain a **3D** representation of the surface that is named 'wire-frame'. The azimutal 'angle of view' of this **3D** image is determined by the shift value Δz, while a polar rotation of the angle of view may be obtained by applying a shift Δx to each x-line profile.

In **Fig. 1.** we report an image obtained with commercial SFM operating at constant force[2] (square matrix of 256x256 pixel where lighter dots indicate larger z values): the single atomic layers in a Gallium Arsenide single crystal substrate are evident, as well as some Indium

Arsenide nanostructures (white dots) grown onto the substrate by Metal Organic Vapor Phase Epitaxy.

Working principle of the 'macroscope'

Our device is based on the technology of 'stylus profilometers'. The commercial profilometers work in one dimension, generating a line-profile of the investigated sample, while our device must scan a surface by moving the probe along a series of parallel lines (the raster scanning normally used by SFM when storing bitmapped images in a matrix). A simple software for real time data acquisition may be used to build a profilometer by using as a *vertical displacement* probe (z-axis) a tip soldered at the end of a cantilever whose deflection is measured by strain gauges and as a *horizontal displacement* sensor (x-axis) a micropositioner whose driving screw rotation angle is measured by a potentiometer

Our device is able to record two series of values (vectors) corresponding to the signal $V^z=V(z)$ of the vertical displacement of the tip following the sample topography and to the signal $V^x=V(x)$ of the potentiometer measuring the displacement along the x axis. On the computer screen it is therefore possible to trace the plot $V_z=f(V_x)$ reproducing the sample profile along a line parallel to x.

A series of scans (each one made for a different position along y-axis) contains information on the whole sample surface, but if we placed them all together in the plot $V_z=f(V_x,y)$ the result would be unreadable, due to the overlap. We therefore used a simple 'trick' in order to make visible the sample topography and to produce a 'pseudo-3D' image. The trick consists of mounting the sample onto a tilted plane so that every displacement along the y-axis produces a vertical shift $\Delta V^z=V(\Delta y \tan \alpha)$

The tip-cantilever system (z-axis displacement sensor) is mounted on a metal holder that may be moved along the y-axis by rotating a driving screw, while the sample-holder performs the x-axis scan. The x-axis movement is obtained using a cheap trolley (a Domino 50, produced by Schluderbacker) whose knob is ganged to the axis of a potentiometer by means of a pulley.

The maximum scan width is limited by the range of x and y screws (in our case about 20mm in both directions). A sketch of the device is shown in **Fig. 2.**

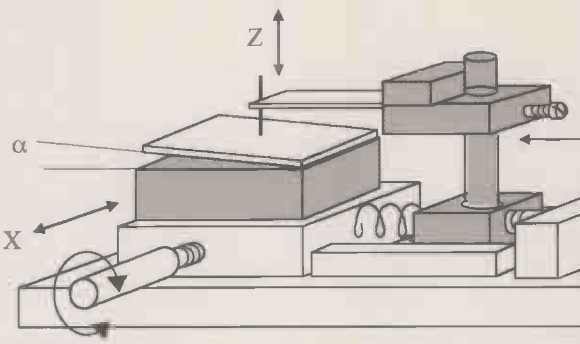


Fig.2. Schematic of the device.

Fig. 3. A picture of our device.

The Z-detector

The strain gauge is made of a thin film resistance incorporated into a plastic strip to be glued to the object whose strain has to be measured. Applying to the film a tensile (compressive) strain increases (decreases) its resistance. The change in resistance ΔR is proportional to the relative length change $\varepsilon=\Delta L/L$, with a gauge factor $G=(\Delta R/R)/\varepsilon \cong 2$. By gluing two identical strain gauges to an elastic cantilever and by connecting them in a Wheatstone bridge with two fixed resistors R, we obtain a force sensor (see **Fig. 4.** and Text Box 2).

Fig. 4. The Wheatstone bridge configuration of the strain gauges resistances R^1 and R^2, and sketch of the cantilever geometry. The actual probe is a needle soldered at one end of the cantilever.

When the tip is pushed upward, with a vertical shift Δz, the cantilever deflection produces the relative change +ε in lower strain gauge and −ε in the upper one. The value of the shift may be written (see Text Box 2) $\Delta z=\varepsilon(2L^2/3a)$, where a is the cantilever thickness and L its length, so that the relative resistance change is $\Delta R/R=G\varepsilon\cong\Delta z(3a/L^2)$. For example for $L\cong30$ mm, $a\cong0.3$mm, we get $(\Delta R/R)/\Delta z\cong10^{-3}mm^{-1}$, a sensitivity comparable with the thermal drift of metallic resistances $\beta=(\Delta R/R)/\Delta T\cong10^{-4}C^{-1}$.

This explains why we use *two* strain gauges instead of one: besides the gain of a factor of two in sensitivity, with matched gauges we make the system unaffected by thermal drifts. The voltage V^A at the strain gauge's midpoint depends on the bridge bias voltage V^g and on the values of the two resistances (R−ΔR) and (R+ΔR): $V^A=V^g/2+V^g\Delta R/2R$. The fixed resistor's midpoint voltage is $V^B=V^g/2$, so that the bridge output signal is $\Delta V=V^A-V^B=V^g\Delta R/2R= V^g\varepsilon$.

For example, with $V^g\cong1V$ and $\Delta z\cong0.1$mm we get a signal $\Delta V\cong1$ mV, requiring a gain of about 1000 in order to match the input voltage range of the used interface (0-5V). The signal measuring horizontal displacements is provided by a potentiometer, biased at 5V, driven by a pulley linked to the micrometer axis through a rubber band. Typical resolution of a Helipot (10 turns potentiometer) is of the order of 10^{-4}, introducing an uncertainty smaller than that due to the ADC (10 bits): e.g. with a trolley moving 2mm per each turn of the driving screw, the 5mV sensitivity gives a theoretical resolution of 20mm, better than the limit imposed by the curvature radius of the thinnest usable needles.

The signal conditioning circuit is shown In **Fig. 5.** It consists of an active bridge, built around IC3, biased by IC1, a REF03 2.5V voltage reference buffered by IC2. The output V_z is amplified to obtain a signal suitable to the input range of our Data Acquisition System (0÷5V). One

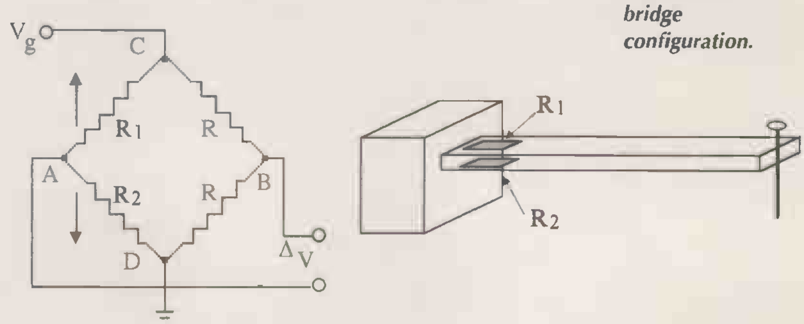


Fig. 4. The Wheatstone bridge configuration.

The BASIC Stamp II code for the stepping motors controller

```
STEP31.BS2

dx      var     bit
sx      var     bit
ay      var     bit
by      var     bit
au      var     bit
i       var     word
j       var     byte

        input 0     'Pin 5 of BS2-IC; RIGHT BUTTON
        input 1     'Pin 6 of BS2-IC; LEFT BUTTON
        input 2     'Pin 7 of BS2-IC; UP BUTTON
        input 3     'Pin 8 of BS2-IC; DOWN BUTTON
        input 4     'Pin 9 of BS2-IC; AUTO SCAN BUTTON
        output 8    'Pin 13 of BS2-IC; CK
        output 9    'Pin 14 of BS2-IC; CW/CCW
signal
        output 10   'Pin 15 of BS2-IC; ENABLE signal for horizontal displacement
        output 11   'Pin 16 of BS2-IC; ENABLE signal for vertical displacement
        dx=0
        sx=0
        ay=0
        by=0
        au=0
        low 10
        low 11
loop:
        buttonå 0å,0,255,1,dx,0,skip1
        gosub dex
skip1:
        button 1,0,255,1,sx,0,skip2
        gosub six
skip2:
        button 2,0,255,1,ay,0,skip3
        gosub aly
skip3:
        button 3,0,255,1,by,0,skip4
        gosub bay
skip4:
        button 4,0,255,1,au,0,skip5å
        gosub aut
skip5:
        goto loop
dex:
        high 10
        high 9
dex1:
        button 0,0,255,1,dx,1,dex2
        low 10
        return
dex2:
        pulsout 8,100
        goto dex1
six:
        high 10
        low 9
six1:
        button 1,0,255,1,sx,1,six2
        low 10
        return
six2:
        pulsout 8,100
        goto six1
aly:
        high 11
        high 9
aly1:
        button 2,0,255,1,ay,1,aly2
        low 11
        return
aly2:
        pulsout 8,100
        goto aly1
bay:
        high 11
        low 9
bay1:
        button 3,0,255,1,by,1,bay2
        low 11
        return
bay2:
        pulsout 8,100
        goto bay1
aut:
        for j=1 to 20
        high 10
        low 9
        for i=1 to 4100
        pulsout 8,100
        next
        low 10
        pause 100
        high 11
        for i=1 to 77
        pulsout 8,100
        next
        low 11
        pause 100
        high 10
        high 9
        for i=1 to 4100
        pulsout 8,100
        next
        low 10
        pause 100
        high 11
        low 9
        for i=1 to 217
        pulsout 8,100
        next
        low 11
        next
        return
```

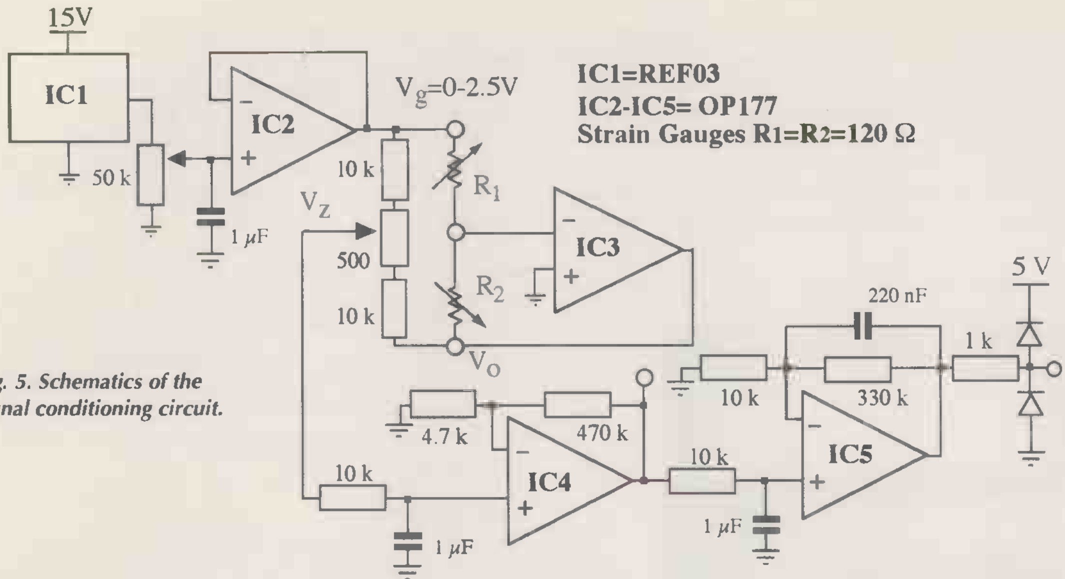


Fig. 5. Schematics of the signal conditioning circuit.

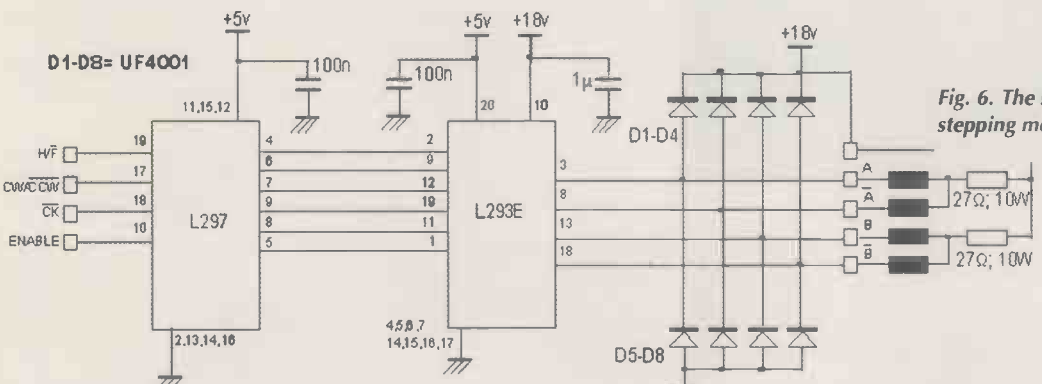


Fig. 6. The simple schematics of the stepping motors drivers.

arm of the bridge is made of the two strain gauges (120Ω) and the other one is made of two fixed resistors (10kΩ) and a balancing potentiometer (500Ω), which allows zeroing of the system before starting scanning a sample.

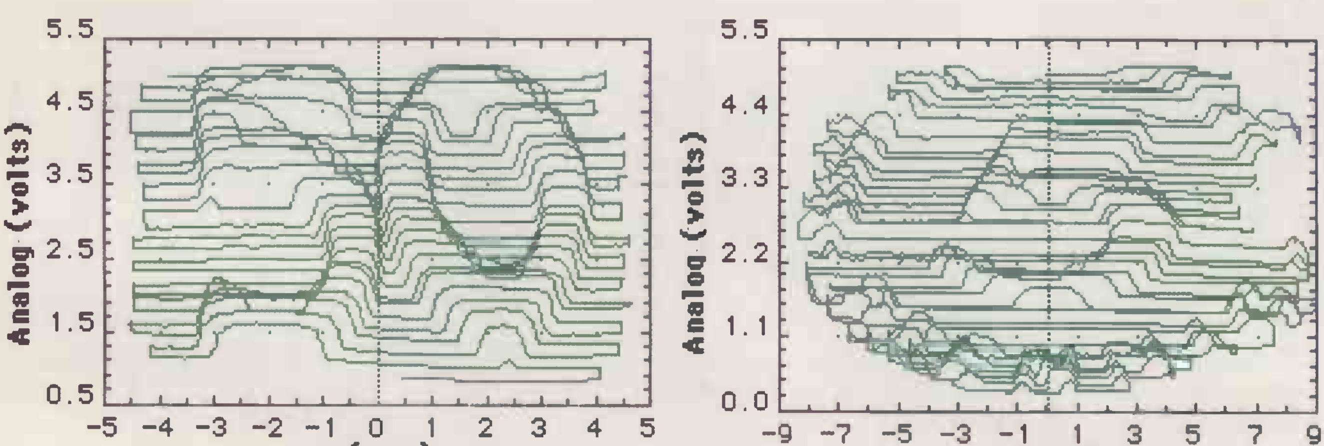
The strain gauges midpoint is kept at virtual ground by the operational amplifier IC3. The bridge is therefore biased by two signals: V_g and $V_O=-(R_2/R_1)\,V_g$, where $R_2=R+G\varepsilon$ and $R_1=R-G\varepsilon$ are the gauge resistances and $G\varepsilon=\Delta R/R$ their relative resistance changes. The output signal $V_z \cong (1/2)(V_g+V_O) \cong 2\varepsilon V_g$, taken at the sliding contact of the potentiometer, is amplified by IC4 and IC5: a differential amplifier is not necessary to amplify the bridge output voltage Vz, given that it is referred to ground. As IC2÷IC5 we have used four OP177 precision low voltage offset and low drift op-amps.

The stepping motors controller

To make the displacements automatic in the x and y axis during the sample scan, we have used for our device a BS2-IC (BASIC Stamp II produced by Parallax, Inc. http://www.parallaxinc.com), a simple and versatile PIC based microcontroller with a BASIC interpreter on board. The BASIC Stamp II program is shown in Text Box 1.

The BASIC Stamp II has 16 Digital I/Os that can be software configured as input or output. We needed five inputs, to sense the state of five buttons (UP, DOWN,

Fig. 7. Profiles of 50 and 5 Pfennig coins.



LEFT, RIGHT, AUTO SCAN), and 4 outputs, to drive the stepping motors. A sixth button, connected to the RESET pin of the BS2-IC makes possible to stop the scan process.

Figure 7 shows the interface circuit that we have used to drive each stepping motor. It is composed by an L297, that integrates all the control circuitry required to control bipolar and unipolar stepping motors, and by an L293E, a quad push-pull driver capable of delivering output currents to 1A per channel. Both pins 17 (CW/$\overline{CCW}$; clockwise/counterclockwise) of the two L297s are connected together. The same for pins 18 ($\overline{CK}$).

The CW/$\overline{CCW}$ and $\overline{CK}$ signals are generated by the BS2-IC pins 14 and 13 (P8 and P9, respectively). The ENABLE signals, for the two L297s come from pins 15 and 16 (P10 and P11) as can be seen in the programme (Text Box 1).

H/$\overline{F}$ (half step or full step) is directly connected to the 'high' logic state. The interface output signals A, $\overline{A}$, B, $\overline{B}$, drive the windings of the stepping motors. We chose the model 15PM-K004 low cost, unipolar, small angle motors by MINEBA CO. LTD. Their holding torque is 650gcm and their current per winding is 0.36A with 8.6V applied. The 27Ω power resistors between the windings common leads and the 18V power supply are necessary to set the current at the correct value.

Fig. 8. The sample coins and the cantilever.

Some images

To give an idea of the capabilities of this device we present in figure 7 some images of coins obtained using 40 lines of 100 points per line; with a sampling frequency of about 4 points per second a total acquisition time of about 10 minutes is required.

A photo of the sample coins (50, 5 and 1 Pfennig, chosen for their small diameter and simple design) is shown in **Fig. 8.**

The images shown in figure 7 were taken using a wool-needle, with a not too sharp tip (whose radius of curvature R=0.28 mm is shown in figure 9a), thus reducing the risk

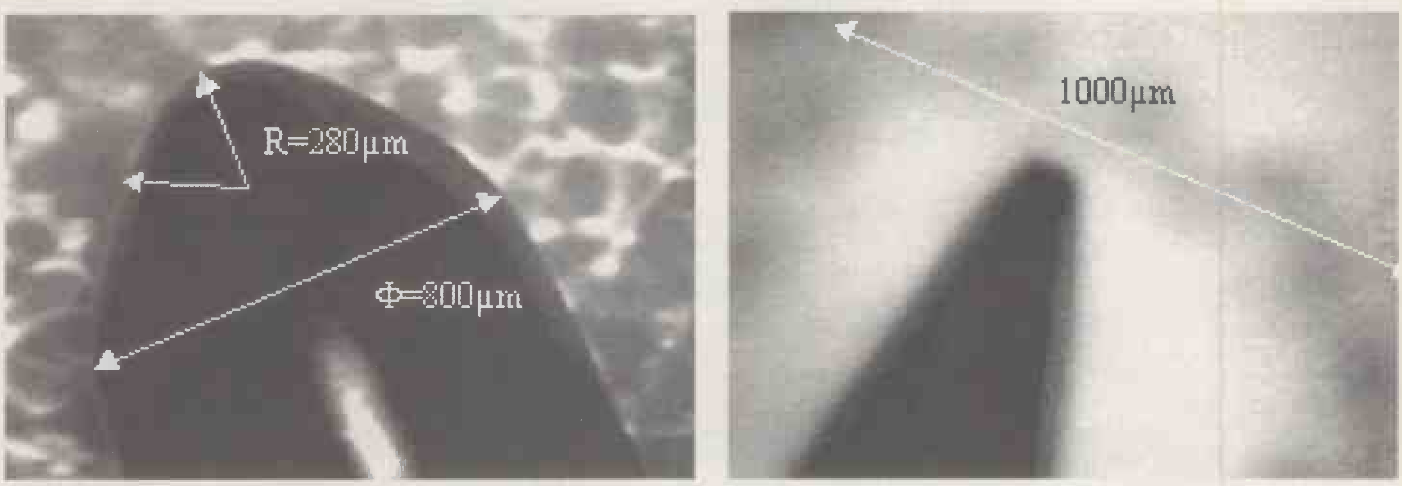


Fig. 9. Photomicrographs of a wool-needle tip (a) and of a sewing-needle tip (b).

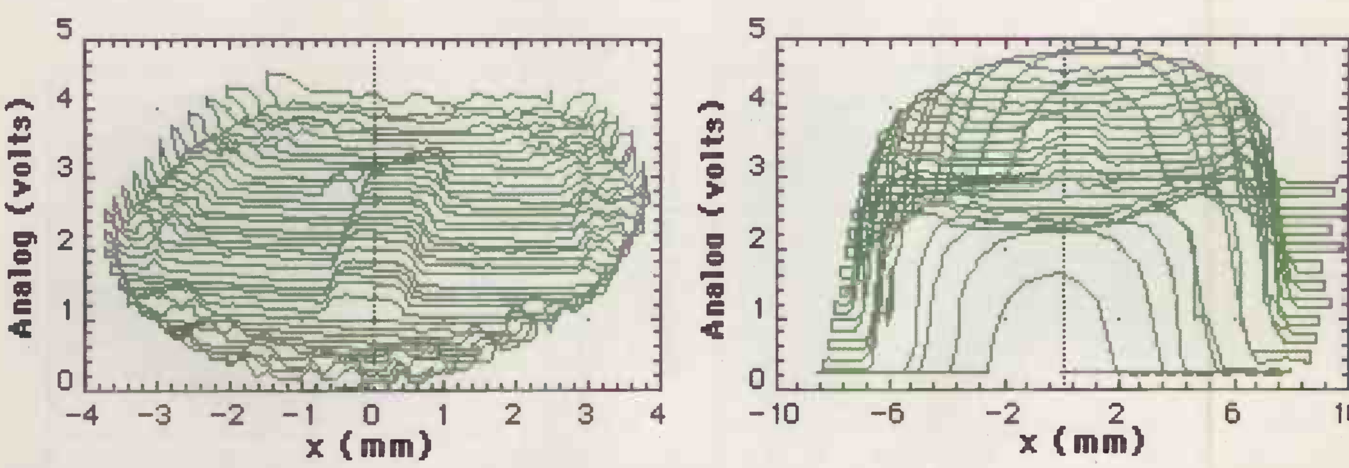


Figure 10: Images of the same sample (1 Pfennig coin) taken with different tips (see text)

of chokes and lateral deflections of the cantilever when crossing sharp steps on the sample. Our device is affected by this problem because it does not have the feedback mechanism that allows SFM to work at constant force: in that case when the tip meets a sample relief, the sample holder is suitably displaced along z to keep constant the cantilever deflection.

Obviously the lateral resolution is better the smaller the tip radius of curvature. To show this effect, that in the language of probe microscopists is named 'tip convolution'[1], we recorded two images, shown in figure 10, of the same sample first using a sharper sewing-needle (R=0.08mm) and then a ball-bearing sphere (R=1.5mm) as probe tips.

Using a curvature radius larger than the coin thickness, we can detect the sample borders (the tip can cross steps slightly smaller than R), but we spoil our lateral resolution. Using a smaller curvature radius we get better resolution, but the probe-sample interaction becomes important (note that in our devices the applied force increases with Δz), so that at the scan end the sample results are slightly damaged (see Text Box 2). The images shown in figures 7 and 10 report the x-axis calibrated in mm. How did we calibrated it? We simply measured the change ΔV^x corresponding to a known displacement Δx to calculate the conversion factor $K^x = \Delta x/\Delta V^x$(mm/V). To calibrate the y-axis we measure the change in the V^z signal produced by a known shift Δy along a flat region of the sample surface: the conversion factor is $K^y = \Delta y/\Delta V^z$ (mm/V).

For the z-axis we have $K^z = K^y \tan\alpha$, where α is the tilt angle between the sample surface plane and the x-y scan plane. ■

References

1 Giacomo Torzo: Dipartimento di Fisica, Università di Padova, INFM and CNR
Barbara Pecori: Dipartimento di Fisica, Università di Bologna
Pietro Scatturin: Dipartimento di Fisica, Università di Padova
Giorgio Delfitto: Dipartimento di Fisica, Università di Padova and INFM

2 For a bibliography on SFM see the websites: http://www.park.com/spmguide/contents.htm, or http://www.spm.genebee.msu.su , or the book Yaminsky I.V., Elensky V.G. *Scanning Probe Microscopy: Bibliography (1982-1997)*. Moscow: Scientific World, 1997. (A Series: Scanning Probe Microscopy; Vol. 2)

3 See G.Torzo and D. Cerolini: *SFM image reconstruction reducing tip artifacts*, Microscopy and Microanalysis, May 2000.

Calculus of the strain ε produced by the cantilever deflection Δz

The strain in elastic bodies is described by the relation $\varepsilon = 1/E \cdot (F/S)$ relating $\varepsilon = \Delta L/L$ to the applied force F, the section S and the Young modulus **E** (for steel $E \cong 22.10^6$ N/cm^2).

We are looking for a relation between the displacement Δz of the free end of a cantilever and ε. Thinking the cantilever (horizontal in equilibrium) as a beam of fibres, a deflection produces an increase of the fibres length on the convex side and a decrease on the concave side, with respect to the median fibre.Now, the length dx of an arc P-Q (figure 11) of the median fibre may be written as product of the curvature radius ρ and angle α : $dx = \rho\,\alpha$.

The relative length change, at the generic distance y from the median fibre is therefore $\varepsilon = \pm y/\rho$, corresponding to an applied tangent force $dF = EdS(y/\rho)$, where $dS = bdy$ is the cross section of the fibre. A cantilever deflection corresponds to an applied torque given by the integral:

$$\Gamma = \int y\,dF = \int y^2 (E/\rho)\,dS = (E/\rho)j$$

where $j = \int y^2 dS = a^3 b/12$.

Because the angle between tangents to the fiber in P and Q is α,the differential contribution to vertical displacement is $dz = x\,dx/\rho$, where x is the distance of P from the cantilever end (tip position). By substituting ρ we get $dz = (\Gamma/Ej)x\,dx$.Neglecting the cantilever weight, the equilibrium between applied torque Fx and the restoring elastic torque Γ gives $dz = (F/Ej)\,x^2\,dx$The total displacement is obtained by integrating along the cantilever length:$\Delta z = (F/Ej)\,L^3/3 = (F/E)(4L^3/ba^3)$.

The strain ε changes along x growing with curvature $1/\rho$, reaching a maximum close to $x \cong L$, where the gauges are glued. Here $\varepsilon = \pm(a/2)/\rho = \pm(a/2)(\Gamma/Ej)$, and the torque is $\Gamma = FL$. From $\Delta z = (F/Ej)L^3/3$ we get $(FL/Ej) = \Delta z/(3/L^2)$ and finally $\varepsilon = \pm(a/2)(FL/Ej) = \Delta z(3a/2L^2)$.Higher sensitivity ($\sigma = \varepsilon/\Delta z$) can be attained by increasing thickness a and reducing length L, but this also increases the tip to sample force $F = \varepsilon E a^2 b/6L = E\Delta z\, ba^3/4L^3$.With a=0.3mm, b=10 mm, L=30mm, the applied force with a deflection of 1mm is 0.25N≅25g, already sufficient to slightly scratch a metal with a sharp needle.

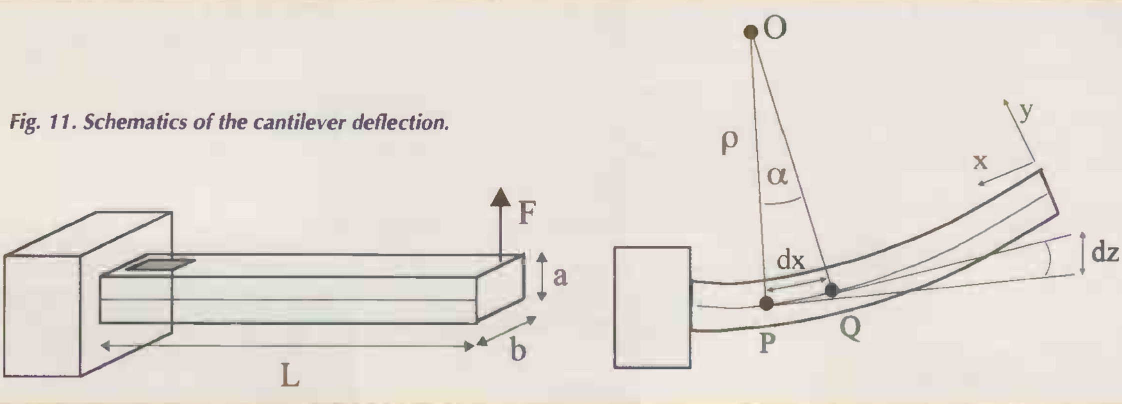


Fig. 11. Schematics of the cantilever deflection.

Please quote *Electronics World* when seeking further information

White LEDs have 35mcd brightness

Rohm has expanded its family of miniature surface mount white chip LEDs with three devices that combine high brightness with low typical and maximum forward voltage (V_F) ratings of 3.0V and 3.3V respectively. Designed to provide enhanced PCB mounting flexibility, the new parts have dimensions down to 1.6 x 0.8 x 0.55mm and are ideal for consumer and telecoms applications, said the supplier. Typical brightness levels for the

new devices are in the region of 35mcd at a forward current (I_F) of 5mA. Maximum I_F is rated at 20mA, while each LED will handle a peak I_F of 100mA (pulse duration 30ms).

Rohm
www.rohm.co.uk
Tel: +44(0) 1908 282284

2-2-2 DDR Dram

Smart Modular Technologies owned by Solectron, now has low latency PC2100 registered double data rate (DDR) memory modules aimed at increasing memory speeds in high performance computing and server applications. The line-up features a 2.1 Gbyte/s data throughput and CAS latency timings of 2-2-2 (CAS) delay, RAS-to-CAS delay, pre-charge). Intel has validated the devices on a Xeon-based Prestonia server reference platform featuring the Plumas-533 chipset (533MHz, front side bus).

Smart
www.smartm.com
Tel: +44(0) 1928 735651

Voltage regulator can be buck or switch

Semtech has a low-voltage current-mode regulator controller that can be configured into a buck, buck-boost

(inverter) or zeta (step-up or step-down) switching-regulator topology. The SC4508 is for driving p-channel power Mosfets to supply up to 6A output current. It accepts inputs from 2.7 to 15V. Its programmable switching frequency, up to 1.5MHz, allows for small capacitors and coils. Output voltage is programmable, through a resistor divider over positive voltages from V(Ref) to 0.9 x V_{in} or, on the negative side, from –1 to –200V. It typically draws about 3mA in normal operation, which drops to 200μA in shutdown mode.

Semtech
www.semtech.com

MPC5200 PowerPC gets RTOS support

Green Hills Software is supporting Motorola's MPC5200 PowerPC processor with its Integrity RTOS, multi integrated development environment and C, C++ and Misra C compilers. This software is for developers of embedded systems for mobile and fixed applications in telematics, gateways, industrial control and electronic and medical instruments. The deterministic RTOS builds on the hardware memory protection facilities of the MMU. It provides a firewall between the kernel and user tasks that prevents errant or malicious code from corrupting user data, the kernel, inter-process communications, device drivers and other tasks. It also runs with interrupts continuously enabled, guaranteeing access to the CPU and memory for critical tasks, even during RTOS system calls. The 400MHz device delivers

Ethernet connector

Pulse has a range of IEEE 802.3af compliant Power over Ethernet (PoE), 10/100BASE-TX transformer modules, specifically designed for mid-span PoE applications. The use of products H1180, H1183 and H1197 upgrades an existing Ethernet connection to a power over Ethernet compliant system, allowing a remote device to receive power and data over the same unshielded twisted pair (UYTP) cable. The H1180, H1183 and H1197 are placed in parallel (in-line) with the existing UTP Ethernet cabling architecture. Their high input impedance makes each transformer appear transparent to the existing Ethernet system,

instantly upgrading the connection, said the company. This upgrade thus reduces cost and time-to-market for establishing a PoE-enabled system. The components can deliver 15W of power to a remote device located 100m away, making them suitable for remote power-feeding applications such as security camera equipment, wireless networking systems, remote sensors and transducers, and VoIP phones. The modules deliver a minimum of 1,000Vrms isolation and 350mA capability.

Pulse
www.pulseeng.com
Tel: +44(0) 1483 401700

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760Mips and consumes less than 850mW.
Green Hills Software
www.ghs.com

Headphone amp for single-cell designs

National Semiconductor is offering a version of its Boomer stereo headphone amplifier to operate from a one cell 1.5V battery. The LM4916 is unity gain stable. It is a mono differential output (for bridge-tied loads or BTL) audio power amp and a single-ended stereo headphone amp. Operating from a 1.5V supply, the mono BTL mode delivers 85mW into an 8Ω load at 1 per cent THD+N.

In single-ended stereo headphone mode, the amp delivers 14mW per channel into a 16Ω load at 1 per cent THD+N.
National Semiconductor
www.national.com

Resolver-to-digital converter option improves accuracy

Data Device has announced an option for its RD19230FX resolver-to-digital monolithic converter that provides an accuracy of one arc minute. Resolver-to-digital converters take analogue AC inputs from resolvers, which are rugged angular transducers, and convert them to digital angular format. The device also provides programmable 10, 12, 14 and 16-bit resolution, dual

bandwidth and tracking rates, +5V only input power, internal synthesised reference, and A quad B encoder emulation. Applications include motor control, radar antenna position, machine tool control, robotics and process control. Available with operating temperatures of –40 to +85°C (FX-205) and 0 to 70°C (FX-305), the converter is in a 10 by 10mm, 64-pin, plastic quad flat pack.
Data Device
www.ddc-web.com
Tel: +44(0) 1631 567 5600

5V reference accurate to ±0.5mV

Xicor has introduced 5V reference devices which it claims offer a guaranteed absolute initial accuracy as low as ±0.5mV, straight-line temperature coefficients of 5ppm/°C, and a long-term stability of 10ppm/1000 hours.

Power consumption is 500nA of supply current. Both devices feature a noise voltage figure of 30μV p-p (0.1 to 10Hz), and an operating temperature range of –40 to +85°C. They are the first devices in an extensive family of precision voltage references manufactured using Xicor's proprietary FGA technology, which the firm claims achieves performance levels that exceed conventional burid-zener and band-gap technologies.
Xicor
www.xicor.com
Tel: +44(0) 1993 700544

Tiny dual PLL runs up to 6GHz

Fujitsu Microelectronics Europe has announced the MB15F7xUV series, sub-miniature dual PLL frequency synthesisers for high frequency mobile comms. The design of the PLLs enables the devices to be housed in the industry's smallest PLL enclosure, claims the firm, an 18-pad 'bump chip carrier' measuring 2.4 x 2.7 x 0.45mm. Fabricated in Fujitsu's 0.35μm BiCMOS, the family is capable of operating from 2.4 to 3.6V.
Fujitsu Microelectronics
Tel: +44(0) 049 6103 6900

Modular PSUs with increased output

Astic Power has added new output power ratings to its MOP modular power supply series. The existing four MP models now deliver an extra 200W of output power at high line voltage when compared to their universal voltage ratings. Four chassis sizes are available. These enable installed output modules to deliver maximum power levels of 600W, 800W, 1,000W and 1,200W to their designated loads when operated at high line. Each chassis can be configured with almost any combination of more than 25 commercial-off-the-shelf output modules to provide a variety of output voltage combinations from 2V to 60V with output current capacities from 0.5A to 120A. Each chassis can accommodate up to seven output

Power supply packs it with plug-in modules

A configurable power supply that packs up to 700W into a chassis that measures 266.7 x 127 x 63.5mm has been introduced by XP. The F7 modular AC-DC power unit uses plug-in modules to provide up to nine floating outputs between 1.9 and 150V DC. Outputs can be connected in series or parallel, the latter using active current sharing. The rugged design has a universal AC input with integral power factor correction and 40A maximum peak inrush current. The outputs are adjustable by ±5 per cent and have maximum ripple and noise of 50mV or 1 per cent peak-to-peak, whichever is greater. Line regulation is typically 0.1 per cent and load regulation is 1 per cent maximum for single output modules and 2 per cent for dual or triple output modules. It has over-voltage protection at 115 to 140 per cent of nominal, depending on the individual module and output, and overload protection which operates at 140 per cent of nominal rating. The signal set includes a TTL-compatible inhibit function, DC OK signal, power fail indication and a 5V 1A housekeeping rail.
XP
www.xppic.com
Tel: +44(0) 1271 856666

Please quote *Electronics World* when seeking further information

modules. The modules are suited to computing, networking, office systems and data communications.
Astec Power
www.astecpower.com
Tel: +44(0) 031 24372 3212

Mobile test platform for 3G troubleshooting

Tektronix has available a mobile protocol test platform equipped with application software to test complex third-generation (3G) and existing second-generation (2G, 2.5G) mobile networks. According to the company, the test platform and supporting application software allows operators to resolve service degradation warnings within minutes with multi-interface call trace and automatic UMTS configuration. The real-time troubleshooting capabilities of the application software should also allow technicians to automatically configure monitoring parameters, correlate data coming from multiple interfaces and locate the root cause of faults while sustaining high data capture rates. Technologies supported include UMTS, CDMA2000, cdmaOne, EDGE, GPRS and GSM.

Tektronix
www.tektronix.com
Tel: +44(0) 01344 392241

Power rocker switches

The CG and CL series of panel mount power rocker switches from ITT Industries, are targeted at small appliances, instrument panels, industrial controls, floor care products, and computers and peripherals. The CG series can be supplied with a two tone actuator or can be illuminated with white, red, amber, or green actuators. Additionally, the actuators can be marked. The CL series feature a positive detent and were designed for easy snap-in mounting. With constant ratings of 16A at 125VAC or 10A at 250VAC, both series have UL and CSA approvals. The CG series also have VDE approval.

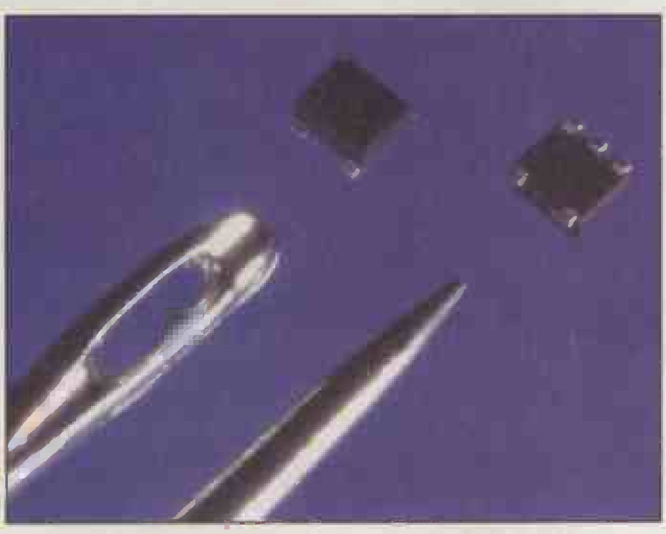
ITT Industries
www.ittcannon.com
Tel: +44(0) 01 617 969 6600

Kits adapt test equipment for cars

Fluke has introduced two kits aimed at technicians working on automotive systems. Designed for use with any handheld Fluke ScopeMeter, the kits include suitable shielded and heat resistant test leads, probes and clips together with PC compatible software. The SCC128 Auto Kit is designed for use with a 20MHz or 40MHz bandwidth, 5000 counts true-RMS 120 Series ScopeMeter, and the SCC198 Auto Kit for use with a ScopeMeter from the up-to-200MHz and 2.5Gsample/s 190 Series. Both kits contain FlukeView for Windows software and an optically isolated connecting cable. A library of named test set-up waveforms and measurements can be built up and uploaded to the ScopeMeter for comparison in the field. Captured waveforms, screens and measurement data can be downloaded to a PC for archiving, printing or importing into reports.
Fluke
www.fluke.co.uk
Tel: +44(0) 20 7942 0700

Smallest single-gate logic devices

Toshiba claims to have the smallest single-gate logic device. The logic-MOS (LMOS) device comes in a miniature style FSV package measuring 1.0 by 0.48mm. According to the supplier, board-mounting area can be 76 per cent less than previous generation USV (SOT353) alternatives and over 60 per cent less than miniature ESV packages. The TC7SHxx devices operate with a supply voltage between 2 and 5.5V and offer a typical propagation delay of 3.7ns. Output current is 8mA, with power dissipation 50mW. All devices incorporate input power down protection as standard. The range includes two-input NAND, two-input AND, two-input NOR, two-input OR and two-input EX-OR single-gate logic functions, as well as various inverter and buffer options.



Toshiba
www.toshiba.com
Tel: +44(0) 049 211 5296 254

Custom oscillators up to 2.4GHz

RFX use PLL techniques to produce custom oscillator modules, with frequencies up to 2.4GHz, from a high base oscillator. The oscillators may be locked to an internal or external high precision reference resulting in a very high precision clock. Jitter levels of 0.5ps can be achieved together with excellent phase noise and low ageing characteristics producing accuracies to 0.005ppm max./day. Modules are available with ECL or sine wave output. Applications are communications equipment, instrumentation and system synchronisation.
RFX
www.irfx.co.uk
Tel: +44(0) 01506 873797

Battery-backed PSU has modbus functions

The Oracle 111 200 battery-backed switch-mode power supplyfrom VXI Power has a built-in RS232/RS485 interface with modbus functionality, so it can be controlled or monitored remotely. As well as logging data on historical holdup events, the PSU lets the user monitor parameters such as system load

JOHN RADIO ELECTRONIC TEST AND COMMUNICATION EQPT.

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or battery test cycles. The power supply incorporates a two-stage charger with power shift software to reduce battery recharge time. Operating from an 85-264V AC autoranging input, the PSU is available in 12 and 24U versions.
VXI Power
www.vxipower.com
Tel: +44(0) 1522 500511

Devices allow digital Internet link

Epson has introduced the SIS61000 and SIS65000 TCP/IP network device products to let users develop and connect digital electronics to the Internet. The SIS61000 is an open-platform network controller that provides a development environment with the source code disclosed. The SIS65000 is a network controller that lets a camera network be built simply by connecting camera modules. Applications are in white goods, intelligent building, industrial and manufacturing control, transaction and payment terminals, POS, Soho, laboratory measurement equipment, sensors and monitoing, remote data collection equipment, network cameras, video projectors and protocol converters such as serial-to-Ethernet. The SIS61000's network connection is via simple command operations using the firm's network control procedure. It controls devices from the network via general-purpose I/O pinsI^2C bus, and is usable as a main processor thanks to its ARM720T with unified cacheCPU and open hardware and open software. The SIS65000 is a dedicated network camera controller. Based on the SIS61000, it is further outfitted with a camera interface and JPeg encoder, Pictures can be transmitted at up to 7.5fps in VGA size. Features include PC-less Internet camera function capability, compatibilty with various camera modules, up to VGA size and rewritable JPeg encoder table. Energy-saving is done by using a timer or other device for intermittent starting or stopping. A wireless LAN interface is supported.
Epson
www.epson-electronics.de.
Tel: 49 8914 005363

White LED for high end lighting

Vishay Intertechnology has added to its TLCx5100 LED series with the TLCW5100, a 5-mm white LED for high-end lighting applications. The TLCW5100 is a clear, non-diffused LED with 0.33 chromaticity and typical luminous intensity of 4000 mcd. The LED has a 9° angle of intensity and an untinted plastic lens. The TLCx5100 series serve as energy-saving alternatives to incandescent lamps in a broad range of applications.
Vishay
www.epson-electronics.de.
Tel: 49 7131 67 2831

Humidity controllers blow hot and cold

Available from distributor Switchtec, Vemer measurement and regulation controllers for temperature, humidity and pressure can be used for most industrial applications, but particularly the air conditioning, heating and refrigeration industry. Such applications include chill cabinets as used in delicatessens and supermarkets. The controllers offer mounting options including 72 x 72mm, 32 x 74, panel, and DIN mount. Models with highly visible displays are available comprising three digit, seven segment units. Additionally, one, two or four relay output versions are available for controlling multiple external devices and equipment. Thermoresistances NiPt cover the range –20°C to +400°C, thermoresistances NTC from –40°C to +110°C, and thermocouples JK (Fe-Co and Cr–Al) from –200°C to +1200°C
Switchtec
www.switchtec.co.uk
Tel: +44(0) 1785 818600

Ferrite for transformers

TDK Electronics Europe GmbH has started mass production of its PC95 ferrite core material for use in power supply transformers. The PC95 ferrite addresses the increase in demand for smaller and higher efficiency transformers used in DC-DC converters and inverters, as well as the need to comply to a broader range of temperature conditions. Designed for use in near-optimal conditions over a broad temperature range of 25°C to 120°C, the PC95 is for use in conventional switching power supplies, as well as in the main transformers of DC-DC converters of electric automobiles.
TDK
www.tdk.de
Tel: 49 211 9077 183

Boxes suit handheld or desktop devices

Serpac's range of enclosures has been updated with the S, SL and A series cases for housing handheld, portable and desktop devices, and consisting of two or four piece design,, assembled with four or six self-tappingscrews. The top panel of the SL series is inclined for improved ergonomics when used on a deck, said the supplier. The enclosures come with or without a battery compartment for a 9V PP3 cell. All ranges are made in ABS plastic (UL94 HB) in standard colours of black, grey or almond. Other colours are available on demand. As an option, the S series top panel can be recessed for mounting a membrane keypad or a product label. All include internal screw bosses for mounting PCBs. Accessories include a pocket clip that is welded to the base, replacement A series end panels in infra-red, clear and red Plexiglass, and black or clear self-adhesive feet
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www.serpac.co.uk
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e-mail: sales@olson.co.uk web site: http://www.olson.co.uk

Please quote *Electronics World* when seeking further information

Processor with IPsec accelerator

Renesas Technology has announced the SH7710 32-bit Risc microprocessor with an IPsec accelerator for fast encryption and communication processing. The device also has

two on-chip Ethernet controllers that enable connection to two Ethernet LANs. Both peripherals make it suitable for security enabled devices for networks such as VPN dedicated boxes, home gateway servers, surveillance cameras and IP phones. The SH7710 is based on a SuperH Risc SH3-DSP CPU core that operates at up to 200MHz and achieves a processing capability of 260Mips. The on-chip DSP supports various kinds of middleware, such as a voice codec and echo canceller, and enables fast execution of multimedia related processing such as VoIP. The IPsec accelerator implements security in the IP or network layer and supports Des and 3Des encryption and decryption methods and MD5 and SHA-1 authentication data generation methods. As well as the encryption circuitry, buffer memory and dedicated data transfer DMACs are provided, allowing data transfer directly between external memory and the buffer memory, and between the buffer memory and encryption circuitry, without CPU load and enables communication processing to be executed at speeds upwards of 20 Mbit/s with a VPN configuration when using 3Des processing. Evaluation boards – such as the Hitachi ULSI Systems' Solution Engine and Renesas Technology's E10A simple emulator – are supported as development environment tools. User development of various protocol stacks is supported by the third-party providers.

Renesas Technology
www.renesas.com
Tel: +44(0) 1628 585100

Claim for smallest Schottky diode

The IRI40CSP Flipky device in a standard ball-grid array (BGA) package occupies 2.25mm². According to the supplier, this is 86 per cent smaller than the standard SMA package. The 1A, 40V Schottky diode is a four-ball, 1.5 x 1.5mm device with a height of less than 0.8mm.
The BGA package enables size reduction and better heat transfer away from the die junction to the circuit board. Since this device is made with chip scale packaging, it dissipates heat directly from the die into the air, increasing thermal efficiency. Thermal resistance junction-to-ambient is 75°C/W maximum and thermal resistance junction-to-PCB is typically 55°C/W.

International Rectifier
www.irf.com
Tel: +44(0) 208 645 8003

Filterless class D audio amplifier

Maxim Integrated Products is offering a filterless class D audio amplifier. The Max9712 offers class AB circuit design with no output filters and class AB audio performance (0.06 per cent THD+N), with 90 per cent class D efficiency, says the company. The device uses a modulation scheme that meets FCC radiated emissions standards without the need for an output filter or ferrite beads. It operates over a 2.4 to 5.5V supply, has a fixed gain of 12dB and produces up to 500mW per channel into an 8Ω load. High 70dB PSRR at 217Hz allows operation directly from a single lithium-ion cell without the need for additional supply conditioning. It includes four clocking options to optimise the noise spectrum for a given application. These include three internally generated clock rates and a fourth unique external-clock mode, letting the user control the exact placement of the switching energy. Multiple device scan operate in a master-slave configuration. It comes in 12-pin UCSP (1.5 x 2 x 0.6mm),ten-pin DFN (3 x 5 x 1mm) packages.

Maxim
www.maxim-ic.com
Tel: +44(0) 118 930 3388

Circular Dins for automotive use

ITT Cannon's APD circular DIN72585 connectors are for automotive, transport and industrial environments, including those subject to shock and vibration. Available in one, two, three, four, six and seven way configurations, the connectors come with a bayonet coupling or as a flanged version. The one way circular connector can handle up to 245A using a 50mm square wire cross section. The dual way has two cavities that can accommodate 16mm square wire cross section with a current capability of 74A. Two, three and four contact connectors have a maximum current rating of 30A, while six and seven way products handle 16A.

ITT Canon
www.ittcannon.com
Tel: 49 7151 699 252

Thermistors are linear

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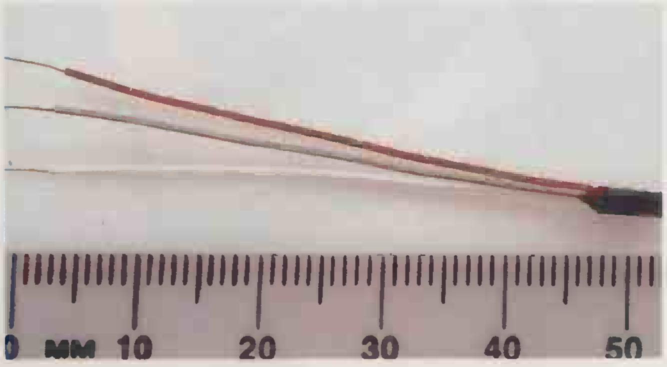

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Fact: most circuit ideas sent to *Electronics World* get published

The best circuit ideas are ones that save time or money, or stimulate the thought process. This includes the odd solution looking for a problem – provided it has a degree of ingenuity. 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. Where software or files are available from us, please email Jackie Lowe with the circuit idea name as the subject.

Send your ideas to: Phil Reed, Highbury Business Communications, Nexus House, Azalea Drive, Swanley, Kent, BR8 8HU *email ewcircuit@highburybiz.com*

Bipolar reference generator from a printer port

Using a small and low cost circuit Fig. 1. with simple control software, you can extend the utility of your PC's printer port for yet another purpose. With your printer port, you can implement a versatile programmable bipolar reference generator by using this circuit. Built using a few readily available low cost components, the circuit occupies a very small space and can be easily attached to the printer port of your PC. You can effectively use this programmable reference generator as a 'stable reference source' for testing your circuits without going for a big, mains powered general-purpose reference generator or any PC add on cards. Further, with this design, you need not turn pots or set thumb wheel switches for setting or changing the reference output to any desired value. All you need to do is just enter the desired voltage and the PC does the rest to set the reference output to the desired bipolar value!

As shown in Fig.1. the circuit uses a low power, programmable 13-bit DAC (IC1, MAX5130), a programmable inverting amplifier (IC2, OP07) and a polarity control switch (IC3, MAX4541CPA). The PC, depending on the reference output required by the user, controls the DAC using three-wire serial interface. Thus the data lines D_0 to D_2 of the data port (0x378h) of printer interface are used by the PC for sending the Chip Select (/CS), data(DATA) and clock (CLK) signals to the DAC. Depending on the data sent by the PC, the DAC produces a voltage output in the range of 0-4.0955 volts in 8192 steps with a step resolution of 0.5mV. Thus data of 0x4000h to the DAC produces the DAC output of 0.00volts while the data of 0x5fffh results in the DAC output of 4.0955volts. Using the 2.5 volts internal reference available in the DAC itself, the output of the DAC and the data input are related as per the following equation:

$$V_{out} = +/- (2.5 * (DATA/8192)*GAIN)$$

where DATA is the decimal equivalent of binary data sent to the DAC and GAIN is the gain of the DAC's

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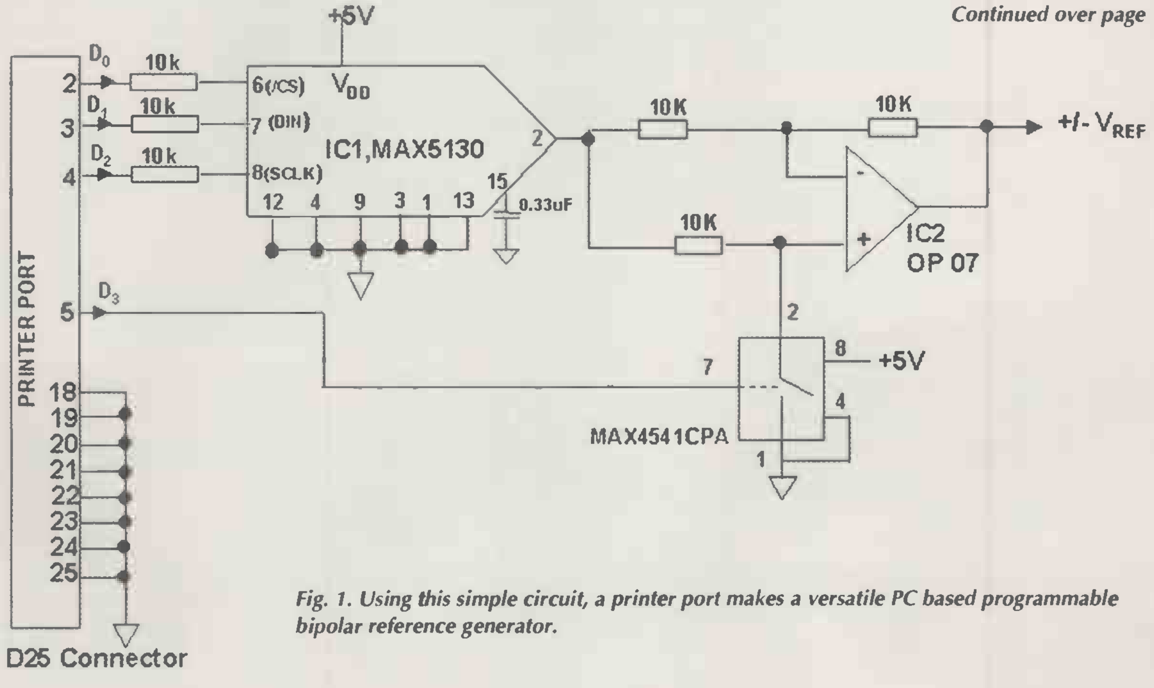

Fig. 1. Using this simple circuit, a printer port makes a versatile PC based programmable bipolar reference generator.

Listing 1

```
/***Turbo C program for "Printer port implements a pro-
grammable bipolar reference generator***/

          /******Author: K.Suresh, MSD, IGCAR, Kalpakkam,
Tamil Nadu, India 603102****/

#include<stdio.h>
#include<conio.h>
#include<math.h>
#include<bios.h>
#include<dos.h>

#define CLK1 0x04       /* Clock Pulse High*/
#define CLK0 0xfb       /* Clock Pulse Low*/
#define CS1  0x01       /* Chip Select high to deactivate
DAC*/
#define CS0 0xfe                                      /*
Chip Select low to activate DAC*/
#define DATA1 0x02                                /* Data
Pulse High*/
#define DATA0 0xfd                                 /* Data
Pulse low*/
#define PLUSVREF 0x00                           /*Vref
=positive*/
#define MINUSVREF 0x08                        /*Vref=nega-
tive*/

int c[16],dport,ACTUALDATA,out,k;   /*Global Declarations*/
float Vref ;/*Desired Reference output*/

void d2b(unsigned int x, int*c)/*Routine for Decimal to
Binary Conversion*/
{
int i;
for(i=0;i<=15;i++)
*(c++)=(x>>i) & 0x1;
}

float SETREF(void)   /*Routine for getting the required
reference output from the user*/
{
int Vin;
printf("\n Enter the desired reference output Vref( -4.0955
V to 4.0955V):");
scanf("%f",&Vin);
while((Vin<-4.0955)|| (Vin>4.0955))
     {
      printf("\n ERROR!!! Vref Out of Range(-4.0955 V to
4.0955V)!");
      printf("\n Press any key to continue");
      getch();
     printf("\n Enter the desired reference output Vref( -
4.0955 V to 4.0955V):");
     scanf("%f",&Vin);
    }
Vref=Vin;
printf("\n Your Desired Reference is  =%f\n",Vref);
return Vref;
}

void SETPOLARITY( float Vref ) /* Routine for setting the
Vref Polarity*/
{
if (Vref<0.0)
{
    out|=MINUSVREF;
   outportb(dport,out); /* Set the Vref polarity as nega-
tive*/
 }
else
{
     out|=PLUSVREF;
     outportb(dport,out); /* Set the Vref polarity as
positive*/
 }
}

void CLOCK_DAC(void)/*Routine for clocking the DAC*/
{
out|=CLK1;
outportb(dport,out);/*Setting the clock high*/
delay(1);
out&=CLK0;
outportb(dport,out);/*Setting the clock low*/
delay(1);
}

void LOAD_DACDATA(int*c)/*Routine for loading actual data
into the DAC*/
{
out|=CS1;
outportb(dport,out);/*Chip Select high to disable DAC*/
delay(1);
out&=CS0;
outportb(dport,out);/*Chip Select low to enable DAC*/
delay(1);
printf("\nDATA loaded into the DAC=");
for(k=15;k>=0;k-)
{
out|=c[k];
outportb(dport,out);
printf("%d",(c[k]<<1));
delay(1);
CLOCK_DAC();
}
out|=CS1;
outportb(dport,out);
delay(1);
}



main()
{
int v,inc;
float y;
unsigned  int x;
double fraction, integer, number;
clrscr();
printf("\tPrinter Port as a Programmable Frequency
Generator");
printf("\n\t\t\t by\n");
printf("\tK.Suresh,MSD,IGCAR,Kalpakkam,TamilNadu-
603102,India");
dport= peek(0x40,8);/*Check up for availability of Printer
Port*/
if (dport==0)
{
printf("\n\n LPT NOT AVIAILABLE! EXITING........");
exit(1);
}
printf("\n\nAddress of the printer port found
=0x%X",dport);
SETREF();
out=0x00;
SETPOLARITY(Vref);
y=(Vref*8192)/(2.5*1.6384);
v=y/1;
number=y;
fraction = modf(number, &integer);
if (fraction<0.44)
inc=0;
else inc=1;
ACTUALDATA=16384+v+inc; /*Actual data including the Control
Word for DAC*/
d2b(ACTUALDATA,c);
LOAD_DACDATA(c);
return 0;
}
```

internal amplifier, usually set to 1.634.

Normally the DAC output is unipolar (positive) only. As is normally done, you can also operate the DAC in bipolar mode with internal reference with an additional op amp as specified in the device data sheet. But here the range of the output is limited to –2.499V to +2.499V (for MAX5130) only. However, the present design enables you to overcome this and get an extended range of reference of –4.0955V to +4.0955V with a step resolution of 0.5mV. As shown in the Fig. 1, you can achieve this extended bipolar output by using the programmable inverting amplifier (IC2) and the polarity control switch (IC3) combination. Depending on the control signal output at Pin 5(D_3 of Data Port 0x378), the polarity control switch is either closed (D_3=logic 1) or open (D_3=logic 0). This makes the programmable inverting amplifier function either as a unity gain inverting amplifier or as a unity gain buffer. If a positive reference output is required, the switch is opened by sending 0V (<0.8V, logic 0) at D_3 making IC2 work as a unity gain buffer. Then the DAC positive output is buffered by IC2 before being available at the output as $+V_{REF}$. When a negative reference output is needed, the switch is closed by sending a +5V(logic 1) at D_3 and the positive DAC output is amplified by IC2 with a gain of –1. The desired $-V_{REF}$ is now available at the output. Thus by controlling the 16-bit data sent to the DAC and the polarity control switch, the programmable reference generator can be made to output any user desired output.

The control software for this bipolar reference generator written in Turbo C is given in Listing 1. The software obtains the desired Vref from the user, checks the set value lying within the range of –4.0955V to +4.0955V. If it lies within the range, the program proceeds further. However, if the set value lies outside the allowed range, an error message warns the user about the over range and asks the user to input a correct Vref. When the desired Vref lies within the allowed range, the program first sets the polarity of the desired Vref by sending appropriate logic signal at pin 5 of the printer port and then calculates ACTUALDATA to be sent to the DAC. The d2b routine converts the ACTUALDATA into 16-bit binary data. The program then enables the DAC (/CS= low) and then serially clocks the binary equivalent of ACTUALDATA, starting from MSBit to LSBit, one by one, to the data pin of the DAC. With LSB set at the data pin, the low to high transition of the clock latches the ACTUALDATA completely into the DAC. Now the user set Vref is available at the output!

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Kalpakkam
Tamil Nadu

Current-to-current converter

A current to current converter may often be needed if you have a fixed reference current source of current of the order of say, tens of microamperes and would like to have a current higher or lower than this for your application and to switch or change the direction of the input reference current.

Non inverting Current-to-current converter

You can build a programmable current source of any value higher than input current just by adding two resistors R_1 and R_2 to a unity gain buffer\voltage follower as shown in **Fig 1. a & b**.

The input current I_1, from an external current source that is to be scaled up flows through R_1 (assuming that the bias current of the op amp is negligible) and creates a voltage drop I_1R_1 across R_1. Since the voltage follower has a severe negative feedback, the error voltage across its inverting and non-inverting input terminals should ideally be zero. Therefore the potential at the output of the op amp has to be same as the potential at the non-inverting input. Since one end of R_1 and R_2 are tied together, the potential across R_2 has to be same as the potential across R_1.

Potential across $R_2 = I_2R_2 = I_1R_1$

The output current is sum of the input current flowing through R1 and the current supplied by the op amp flowing through R2

$$I_0 = I_1 + I_2$$
$$= I_1 + (I_1R_1)/R_2 = I_1(1 + R_1/R_2)$$

$$I_0 = I_1(1 + R_1/R_2)$$

The current gain is always greater than unity, which means that the output current to the load RL is always

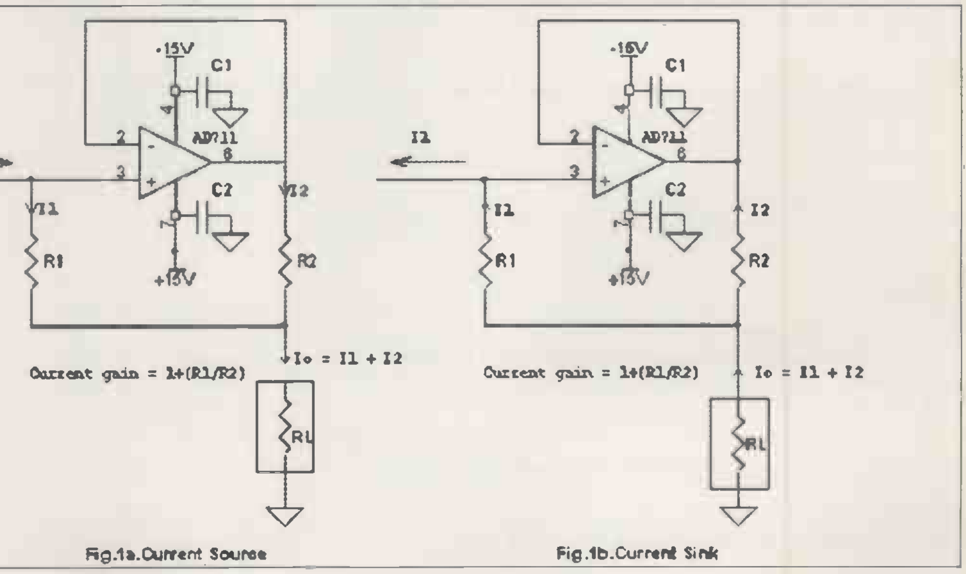

Fig.1.Non inverting current-to-current converter

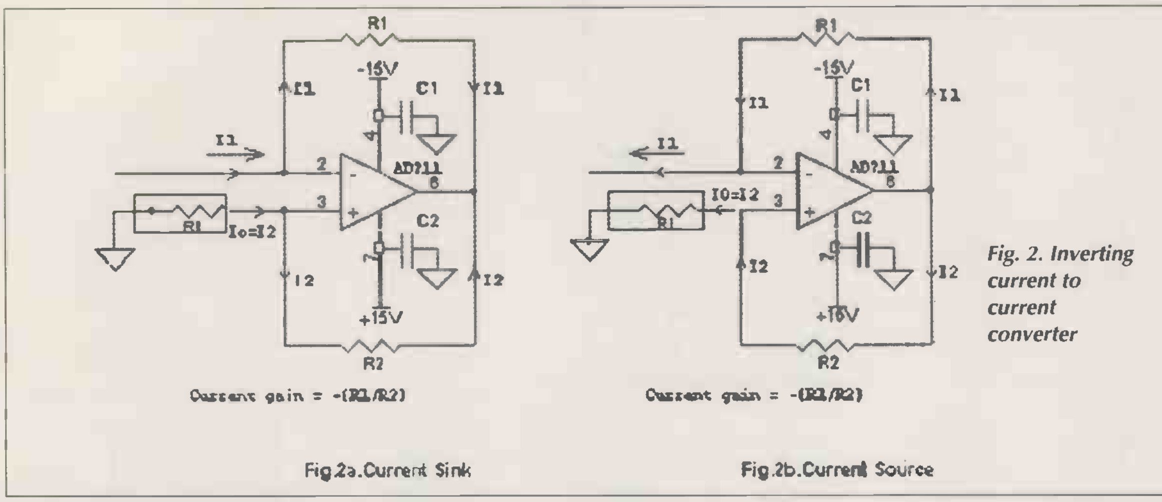

Fig. 2. Inverting current to current converter

greater than the input current. The direction of the current that is delivered to the load is same as the direction of the input current.

The bias current of the op amp determines the minimum value of input reference current that can be handled. An FET op amp with very low input bias current and offset voltage would be a suitable choice for this application C1 & C2 are the recommended decoupling capacitors for the op amp.

Inverting current-to-current converter

Fig. 2. is another current-to-current converter where output current to the load RL can be greater or lesser or equal to the input current with the direction of the output current changed.

The input current from a current source (assuming that the bias current of op amp is negligible) flows through R_1 and creates a voltage drop I_1R_1 across the feedback resistor R_1. The negative feedback forces the potential across inverting and non-inverting input to be zero. Therefore the potential across R_2 has to be the same as the potential across R_1.

$$I_1R_1 = I_2R_2$$

If the bias current of the op-amp is negligible, the current through the resistor R2 and the current through the load RL is same.

$$I_0 = I_2$$

$$I_0 = I_1 (R_1/R_2)$$

An input current I_1 that is sourced out from a current source causes a current I_0 to sink into the load R_L and vice versa as shown in the Fig.2. a & 2b. Therefore I_0 may be written as

$$I_0 = -I_1 (R_1/R_2)$$

The bias current of the op-amp determines the minimum value of input reference current that can be handled. An FET op amp with very low input bias current and offset voltage would be a suitable choice for this application C1 & C2 are the recommended decoupling capacitors for the op amp.

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Using Multiple-purpose Timer Chip to Build Inverting SMPS

Both positive and negative supply voltages are usually required for driving most op-amp. circuits, RS-232 line drivers, A/D and D/A conversion circuits, etc. As the power requirement of these circuits is generally small, an inverting regulator that generates negative supply from the positive one is a preferable alternative rather than employing a full line dual power supply. Despite the fact that this task can be easily accomplished by using a single-chip charge-pump, building an inverting switched mode regulator using an off-the-shelf multiple-purpose chip is interesting as it incorporates the educational aspects of understanding the principles of switched mode power supply.

The circuit being described in this article uses the popular 555 timer chip as a controller for inverting switched mode power supply to generate –5V from +5V supply. The timer is configured as an astable multivibrator with timing controlled by R_1, R_2, C_1, V_{CC}, and upper threshold voltage V_{TU}. The output high time of the timer is determined by the time required to charge C_1 from $-V_{TU}$ to V_{TU} through V_{CC}, R_1, and R_2 that can be expressed by:

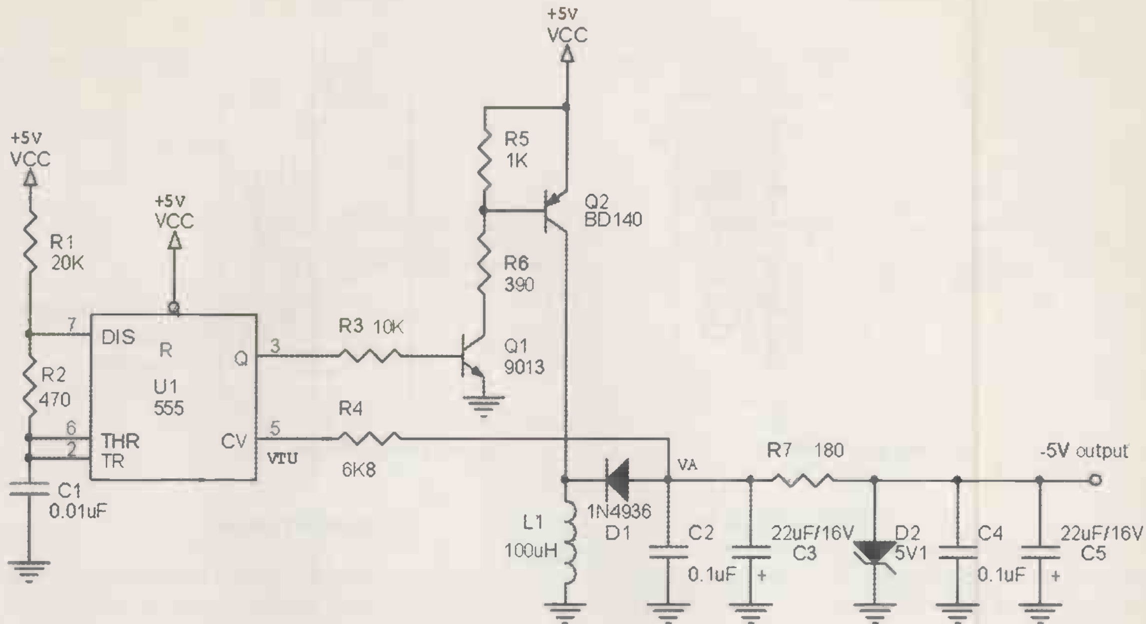
$$t_{hi} = \ln\left[\frac{V_{CC} - \frac{1}{2}V_{TU}}{V_{CC} - V_{TU}}\right](R_1 + R_2)C_1$$

The V_{TU} itself depends on V_{CC}, $3 \times 5\ k\Omega$ internal resistors of the timer chip, feedback circuit R4,
and VA through following equation.

$$V_{TU} = V_{CC} - 5K\Omega\frac{V_{CC}(R_4 + 10K\Omega) + 10K\Omega|V_A|}{15K\Omega R_4 + 5K\Omega 10K\Omega}$$

The output low time of the timer is determined by the time required to discharge C_1 from V_{TU} to $-V_{TU}$ through R_2 and the internal discharge transistor of the chip which can be expressed by:

$$t_{lo} = \ln(2)R_2C_1$$



The buck-boost switched mode regulator circuits consist of Q_2, L_1, D_1, C_2, and C_3. When the output of the timer chip is high during t_{hi}, Q_1 and Q_2 will be turned on and energize inductor L_1. When the output of the timer chip is low during t_{lo}, Q_1 and Q_2 will be turned off and L_1 releases its energy to C_2 and C_3 through $D1$ and thus generates negative voltage V_A. The value of V_A depends on V_{CC}, and also the on and off time of Q_1 through following relation.

$$V_A = -V_{CC}\frac{t_{hi}}{t_{lo}}$$

As t_{hi} itself depends on V_A, the timer chip serves as an active low pulse position modulator that regulates the output voltage. If V_A decreases (becomes less negative), VTU will increase and yield larger t_{hi} that implies higher energy to energize the inductor. This increase in t_{hi} will then restore the intended value of V_A back. The opposite story will take place when V_A increases. Additional ripple filtering and voltage regulation are then carried out by R_7, D_2, C_4, and C_5.

Henri P. Uranus
Enschede Netherlands

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____

____

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Cheques should be made payable to Electronics World

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Credit card no______________________________

Card expiry date Signed

Please allow up to 28 days for delivery

Specifications

Switch position 1

Bandwidth	DC to 10MHz
Input resistance	1MΩ – i.e. oscilloscope i/p
Input capacitance	40pF+oscilloscope capacitance
Working voltage	600V DC or pk-pk AC

Switch position 2

Bandwidth	DC to 150MHz
Rise time	2.4ns
Input resistance	10MΩ ±1% if oscilloscope i/p is 1MΩ
Input capacitance	12pF if oscilloscope i/p is 20pF
Compensation range	10-60pF
Working voltage	600V DC or pk-pk AC

Switch position 'Ref'

Probe tip grounded via 9MΩ, scope i/p grounded

Capacitor & Amplifier Distortions

Cyril Bateman uses his real-time distortion measuring system to investigate capacitor distortions in audio power amplifiers

Assembled using polar aluminium electrolytic capacitors for C1, 3, 9 and 11, my workhorse 100 watt Maplin Mosfet amplifier, tested at 1kHz and 25 watts into an 8Ω load, measured -81.5dB second harmonic, -91.4dB third harmonic, clearly meeting its claimed less than 0.01% distortion[1]. **Fig. 1.**

Replacing the four polar aluminium electrolytic capacitors in this schematic, with the same value and voltage rating bi-polar electrolytics and no other changes, amplifier distortion improved dramatically, becoming -92.1dB second and -94.3dB third harmonic, re-measured a few minutes later. This article is based on more than eighty distortion measurements, taken while investigating the possible reasons for these improvements.

In the past, many amplifier designers have stated that provided the capacitance value is chosen to ensure only a small AC signal voltage drop can appear across capacitors at the lowest frequencies, then capacitor distortion can be ignored.

My original *Capacitor Sounds* series[2] found measurable distortions occurring in un-biased polar aluminium electrolytic capacitors tested at 0.1 volt AC, my smallest practical test voltage. With signals this small, second harmonic of the lowest distortion 100μF 25 volt DC rated polar capacitor I tested, measured -99.5dB with 6 volt bias and -94.4dB with 12 volt bias. Using 0.2 volt AC and larger test voltages, second and third harmonic distortions in polar aluminium electrolytic capacitors increase dramatically, measured with and without DC bias voltage.

Tested using a 1 volt signal, this capacitor's third harmonic remained close to -100dB, with no bias its second harmonic was -93.2dB, increasing to -77.9dB at 6 volt bias and -72.9dB with 12 volt bias. Application of a very small, optimal bias, typically less than 3 volts DC, to selected capacitors may minimise the second harmonic, however for every electrolytic capacitor I tested, further increase of bias voltage resulted in increased second harmonic distortion.

Contrary to the popular belief that a polar aluminium electrolytic capacitor should be biased to 50% rated voltage for minimal distortion, my measurements show that second harmonic distortion can only be minimised by using very small or no DC bias. Any further increase in DC bias increases the second harmonic generated by the capacitor. Application of DC bias at 50% of the capacitor's rated voltage as shown in the figure, results in exceptionally large second harmonic distortions, even for this, the lowest distortion, the best polar capacitor, of those measured. **Fig. 2.**

At very low frequencies, as capacitor impedance increases, signal

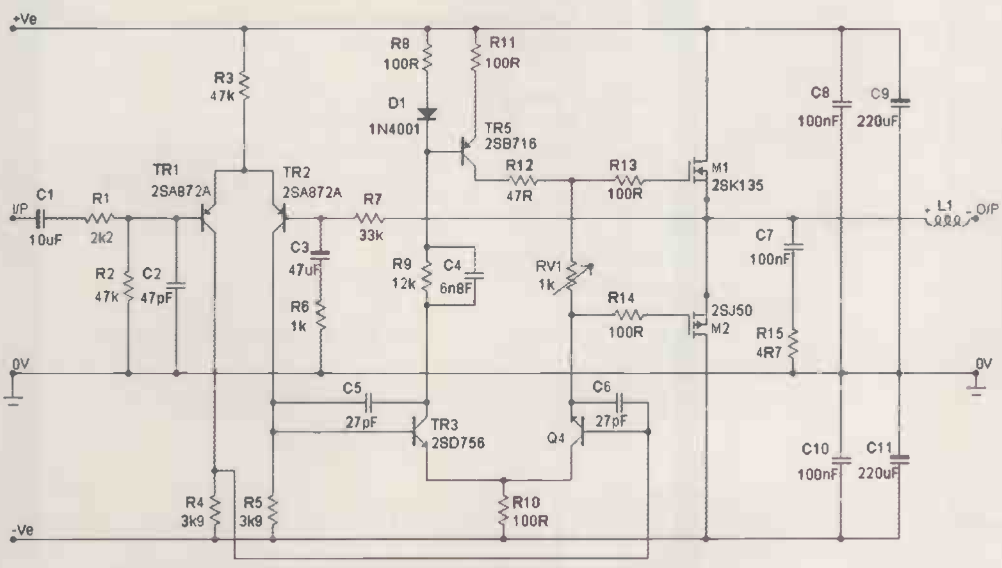


Fig. 1. Schematic circuit of my Maplin Mosfet 100W amplifier, redrawn for convenience using my Microcap MC6 circuit simulator.

voltages could occur in the circuit sufficient to generate measurably increased distortion. However at my 1kHz distortion measurement frequency, all four capacitors have low impedance, so are subject only to small AC signal voltage drops, apparently not sufficient to explain my measured reduction in distortion when replaced by the same value and voltage bi-polar types.

At a given test frequency, capacitor distortions do vary with capacitor AC signal levels and DC bias voltage, but for my Maplin amplifier comparison tests, nominal capacitance values were unchanged so both sets of polar and bi-polar capacitors experienced the same signal voltages. Why should simply changing these capacitors from polar to bi-polar types, provide such benefit?

Capacitor C3 conditions

I ran a few simulations to identify the capacitor most likely to influence this amplifier's distortion. As in many power amplifiers, a 47μF polar aluminium electrolytic capacitor, C3, is used in the feedback network, to roll off amplifier gain at low frequencies, minimising DC offset at its output. With 33kΩ for R7 and 1kΩ for R6, this capacitor is presented with a high impedance for charge and discharge currents. My original *Capacitor Sounds* measurements used lower impedances. Might this high impedance condition affect the capacitor's distortion contributions?

It seemed possible that distortions generated in the capacitor result from two mechanisms, a current dependant component in addition to the voltage component already identified. Throughout that series, I related distortions measured in capacitors to their signal and bias voltages, using test circuit source impedance some two thirds that of the capacitor's at 1kHz for values to 1μF, 100Hz for 1μF and larger values.

I expected to find some third harmonic current dependency from non-ohmic resistances in the capacitor internal connections. Second harmonic distortions in capacitors result from dielectric absorption effects, DC bias and test voltage level, so I wondered whether a change of measuring current with constant bias and test voltage, would reveal changes also in the second harmonic?

In my original *Capacitor Sounds* series I described test equipment designed and built to measure capacitor distortion at 100Hz and 1kHz. For another project last year I assembled a 5kHz test oscillator, buffer amplifier, notch filter/preamplifier, using 1kHz PCBs with smaller tuning and filter capacitors.

Following a few tests, I found this equipment could develop an undistorted 0.5 volt 5kHz signal across my 1μF FKP reference capacitor using 100Ω source impedance. I could measure distortions produced by a 1μF polar aluminium electrolytic capacitor at three test frequencies, 100Hz, 1kHz and 5kHz, using 100Ω source impedance, increasing capacitor test current from 314μA at 100Hz to 15.7mA at 5kHz at constant test voltage. Perhaps that would clarify any capacitor current dependant component.

Using 100Ω source impedance and no bias, I adjusted test levels to develop a 0.5 volt AC voltage across the capacitor at each frequency. Second harmonic distortion increased by 8dB and third harmonic 4.3dB with this change of capacitor current. Clearly both second and third harmonic distortions do increase with capacitor current and AC voltage drop.

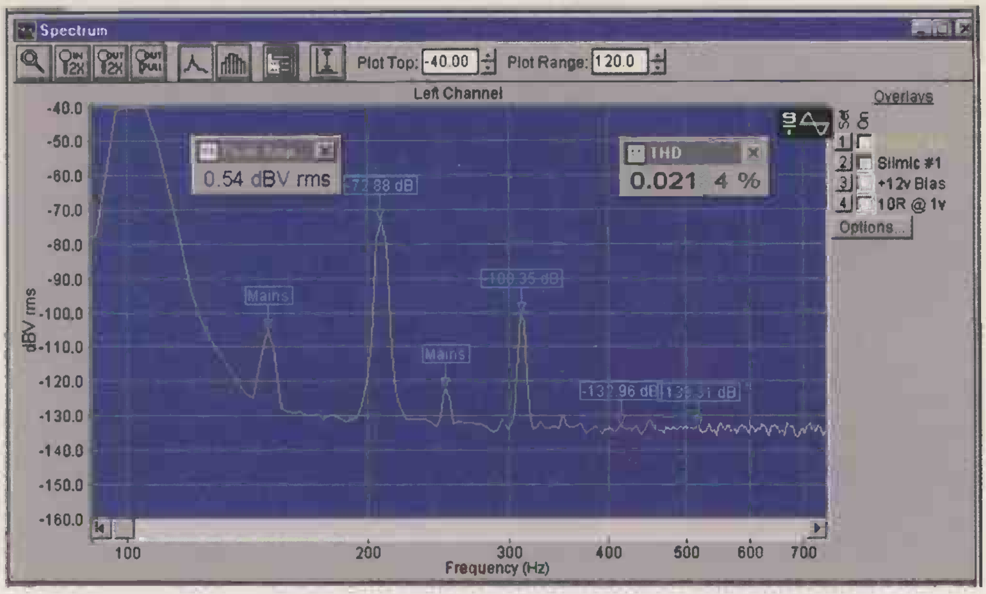


Fig. 2. Distortion results for a Silmic 100μF 25 volt rated polar aluminium electrolytic capacitor, with 12 volt DC bias and tested using 10Ω source impedance generating 1 volt across the capacitor. With no bias, second harmonic distortion for this capacitor was -93.2dB and -77.9dB with 6 volt bias.

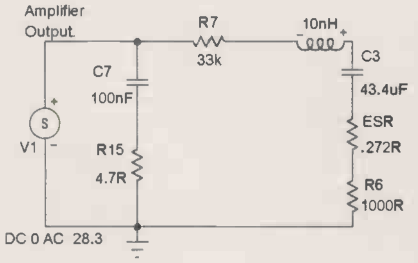


Fig. 3. To simplify my simulations, I extracted the C3 and C7 capacitor sub circuits from the Figure 1 schematic and used the amplifier output voltage as my calculation stimulus. Much simpler, quicker and less prone to simulation errors than when modelling the amplifier.

Second harmonic distortion increases rapidly with DC bias voltage.

Circuit conditions

A few simulation runs using measured capacitance and ESR values by frequency, would establish the voltage and current for capacitor C3, from 10Hz to 20kHz and beyond. Analogue behavioural modelling techniques could be used, but determining the capacitor model can be time consuming and many readers may not have a suitable simulator. Far simpler and quicker - make several frequency runs using measured values for a specific frequency in turn, noting the result for that frequency. This method is practical using the simplest simulator.

Table 1: With 0.5 volt AC test voltage, 100Ω source impedance and no bias, I found second and third harmonic distortion increasing with capacitor current. Clearly both second and third harmonic distortions do increase with capacitor current, voltage drop and second harmonic with DC bias.

Frequency	Impedance	Test Current	Second Harmonic	Third Harmonic	% T.H.D.
100Hz	100Ω	314μA	-107.8dB	-115.7dB	0.00047%
1kHz	100Ω	3.14mA	-102.4dB	-111.6dB	0.00083%
5kHz	100Ω	15.7mA	-99.8dB	-111.4dB	0.00117%

Table 2: Measured values of a 47µF 50 volt Panasonic 'S' bi-polar aluminium electrolytic capacitor as used for C3, with results from my eight simulation runs

Measured Values.				Simulation Results.	
Frequency	Capacitance	Actual ESR	Impedance.	Voltage drop	C3 Current
10Hz	49.08µF	25.74Ω	325.29Ω	270.82mV	832.0µA
20Hz	48.54µF	12.97Ω	164.52Ω	138.02mV	832.03µA
100Hz	45.41µF	1.862Ω	35.09Ω	29.28mV	832.31µA
300Hz	44.24µF	0.575Ω	12.01Ω	10.07mV	832.33µA
1kHz	43.40µF	0.272Ω	3.67Ω	3.05mV	832.35µA
3kHz	42.74µF	0.210Ω	1.26Ω	1.05mV	832.35µA
10kHz	41.71µF	0.191Ω	0.426Ω	0.35mV	832.35µA
30kHz	40.00µF	0.182Ω	0.225Ω	0.18mV	832.35µA

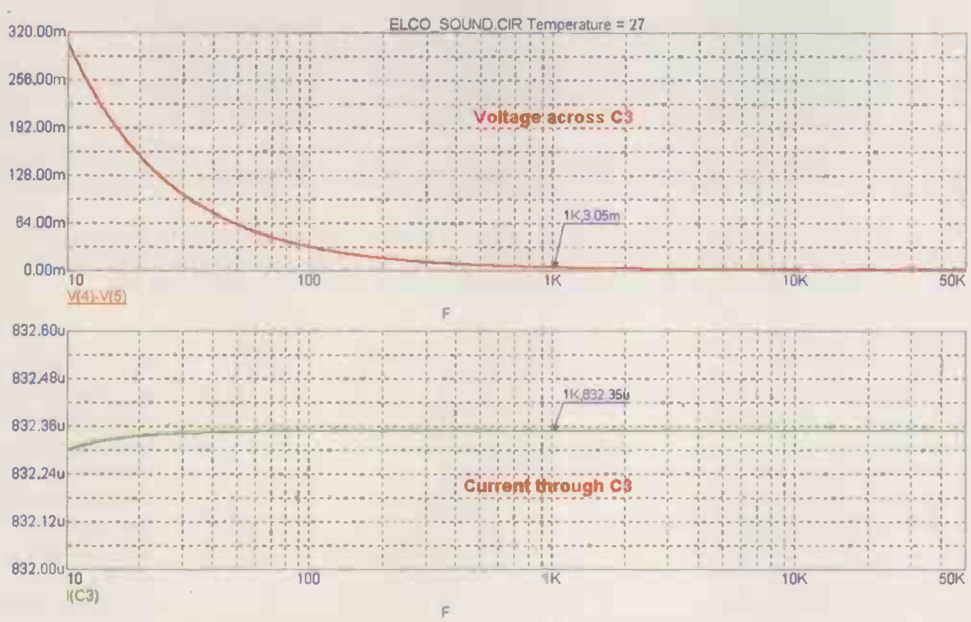
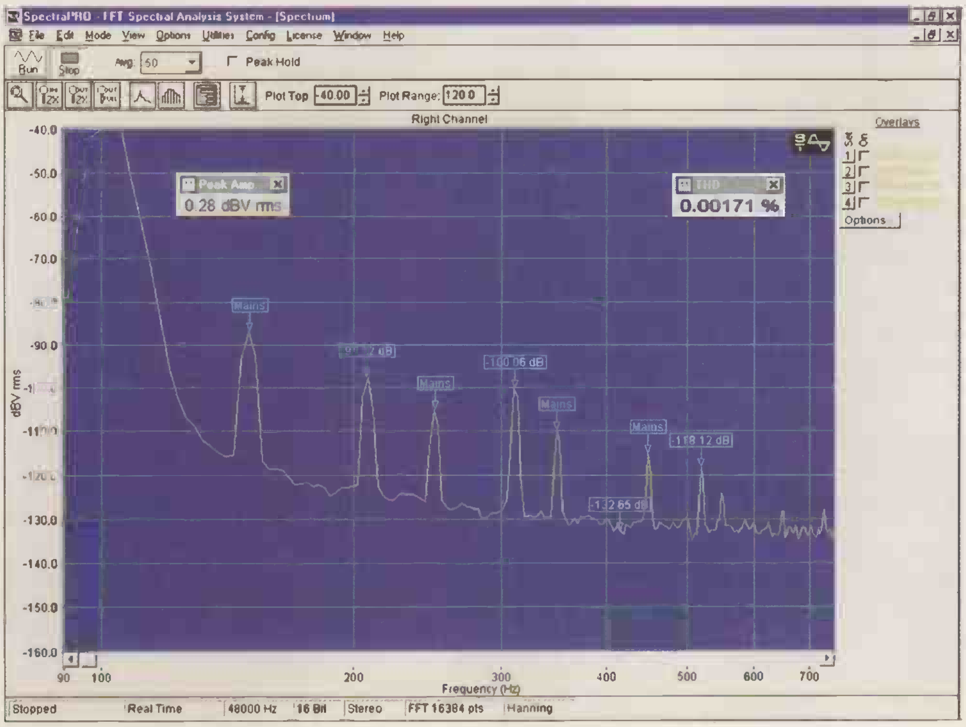


Fig. 4. One of eight simulations needed to accommodate C3 measured parameters by frequency, showing the 1kHz results. Voltage across C3 reduces with frequency but current through C3 remains almost constant regardless of frequency.



I extracted the feedback resistor network with this capacitor from the main circuit and used the amplifier's output voltage for 100 watt into 8Ω as the stimulus. I measured a radial lead, 47µF 50 volt Panasonic 'S' bi-polar electrolytic, the type used when exchanging the capacitors, for capacitance and ESR by frequency. Self resonance was 300kHz, so estimating 10nH for its self inductance, typical of many radial lead aluminium electrolytics in a 20 × 10mm case, completed the model. **Fig. 3.**

Using my Hewlett Packard reference test jig and Wayne Kerr B6425 precision digital LCR meter, I measured this capacitor from 10Hz to 30kHz, for capacitance value and ESR. These pairs of values were inserted into the model in turn for each of eight simulation runs, noting the voltage drop across the capacitor model, from the negative side of the 10nH to the junction of ESR and R6, also C3 through current.

For each run, similar voltage and current plots were observed with subtle changes at the frequency of interest, for the capacitor parameters used. Clearly capacitor signal voltage does reduce with increasing frequency but capacitor current remains almost constant, generating a near constant level of current dependant distortion. **Fig. 4**

Protection Diodes

Most published amplifiers using a polar aluminium electrolytic capacitor for this C3 position add a diode or pair of diodes in parallel, to

Fig. 5. A Rubycon YXF 47µF 25 volt rated polar aluminium electrolytic capacitor tested at 100Hz and 200mV with diodes. Without diodes, third harmonic was -122.67dB, a more than 20dB improvement. At this test voltage, low level AC mains harmonics cannot be eliminated, for clarity test frequency was 103.8 Hz and mains peaks labelled.

protect the capacitor should the amplifier 'go DC' with its output voltage 'stuck' to a supply rail. It has often been claimed such diodes do not distort at the capacitor's signal voltage levels, but I wondered if that were correct. Using a pair of 1N4448 diodes and my 1µF FKP reference capacitor, I made measurements at 1kHz with 100Ω source impedance and test voltages of 75mV, 100mV, 150mV and 200mV, comparing distortion results with and without diodes.

Measured with diodes, third harmonic distortion was visible at -110dB for the 75mV test, increasing to -100dB for 100mV and -84.9dB tested at 200mV, when a fifth harmonic at -100dB was seen. These harmonics result from the diodes conducting slightly at these test voltages since without diodes, my FKP reference capacitor was distortion free.

I measured distortions at 100Hz, with and without diodes, for a variety of 47µF and 100µF polar aluminium electrolytic capacitors, rated at 25 volt and 50 volt, comparing these results with those for the same value bi-polar electrolytics. The results were overwhelmingly conclusive. At 200mV with diodes, third harmonic distortion increased by 20dB with polar and bi-polar capacitors. At 100mV I found smaller increases of third harmonic, depending on the level of distortion generated by the capacitor without diodes. Tested at 0.1 volt with diodes, this capacitor generated -96.8dB second and -108.2dB third harmonic distortion. **Fig. 5.**

I question whether these protection diodes are necessary for polar aluminium electrolytic capacitors in this circuit. They certainly are not needed using a bi-polar aluminium electrolytic capacitor of rated voltage similar to the amplifier's power supply voltage. That capacitor will happily survive indefinitely, regardless of whether the amplifier has 'gone DC' or is working correctly. More important it will generate almost no measurable distortion. **Fig. 6.**

All polar aluminium electrolytic capacitors inherently include a reverse polarity diode[3] so should an amplifier 'go DC', reverse polarising the capacitor by more than 1 volt, capacitor reverse leakage current increases causing a voltage drop across R7. With ±50 volt power supplies and 10kΩ for R7, current cannot exceed 4.8mA. This reverse current may degrade the capacitor which should be replaced during repair, but is most unlikely to result in capacitor failure.

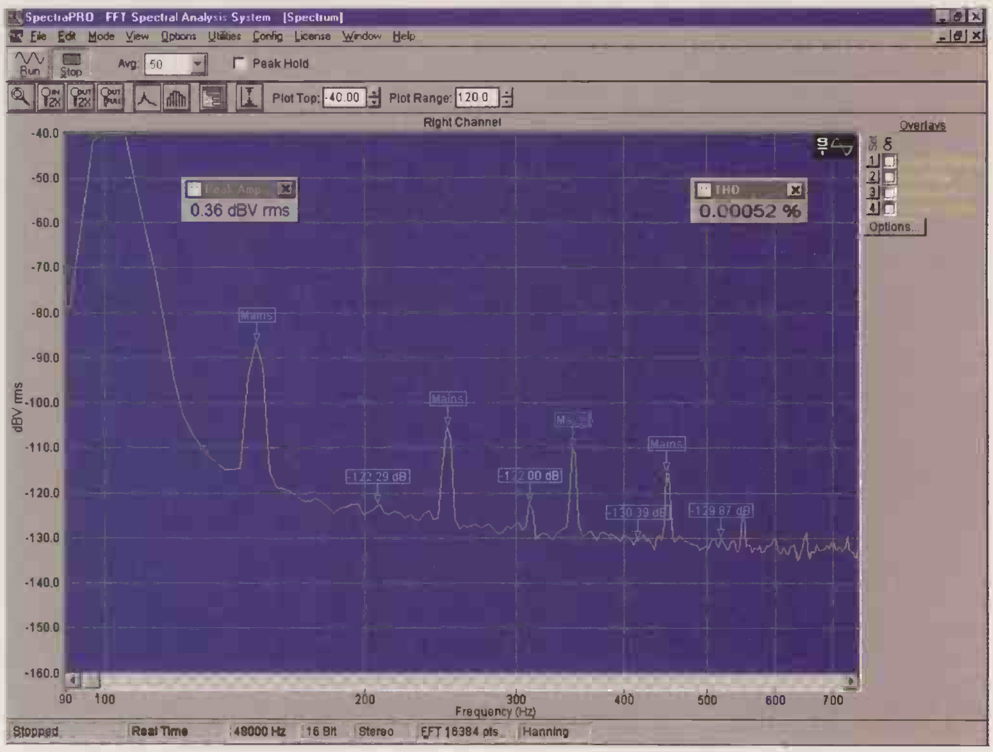


Fig . 6. Without diodes, but otherwise exactly as Figure 5, this Panasonic 'S' 47µF 50 volt bi-polar aluminium electrolytic capacitor shows the distortion reduction available by changing a polar capacitor for a bi-polar type. With diodes, third harmonic increased more than 20dB to -99.24dB, further proof of the diode effect.

Zobel circuit

Many designers have expressed concern to me about the output stage CR Zobel network, that the signal voltage across resistor R15 with this resistor's voltage coefficient might generate audible distortion. With C7 and R15 already modelled, we can quickly explore this Zobel network.

With typical component values of 0.1µF and 4.7 to 10Ω, the 0.1µF capacitor sustains almost all the amplifier output voltage at least to 10kHz and is more highly stressed than the resistor. At higher frequencies, resistor voltage increases but capacitor voltage reduces little.

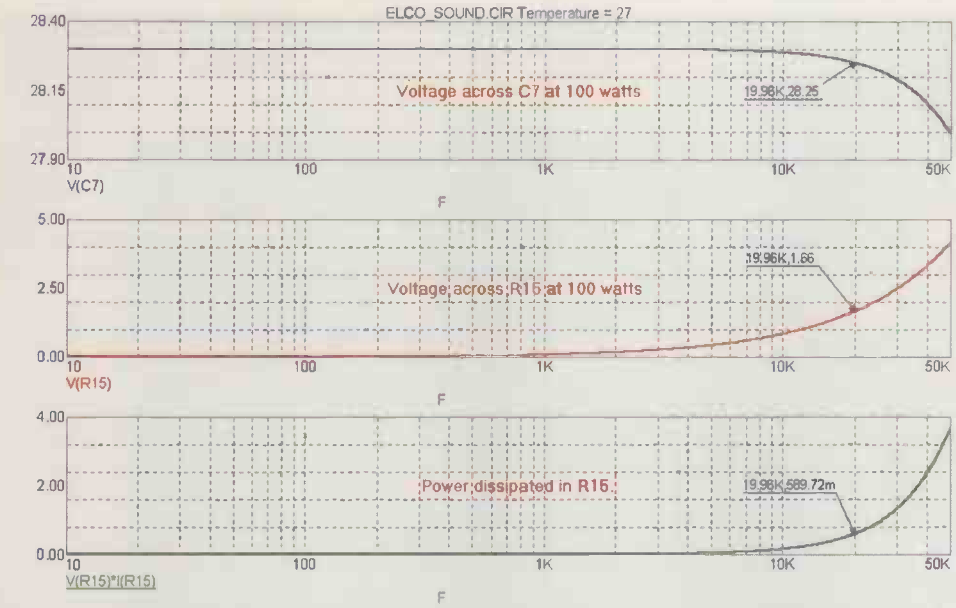


Fig.7. Using the Figure 3 simulation circuit to analyse for C7, we see the capacitor is highly stressed not resistor R15 and badly chosen C7 can generate large distortion. When an amplifier is used for high frequency sinewave tests with or without load, this capacitor frequently fails open, disabling the Zobel, the amplifier may oscillate. Yet R15 is frequently specified as 3 watt rating and C7 ignored.

With 100 watts output into 8Ω at 20kHz, the capacitor must still withstand more than 28 volts while the resistor is subject to less than 2 volts or 0.6 watts. At such voltage a metallised PET capacitor can generate significant distortion. Fig 7.

My test equipment cannot generate that voltage so I measured C7 distortions using an eight volt signal and 100Ω source impedance, equivalent to 8 watts power output, representative perhaps of normal listening. I measured a 0.1µF 'stacked' metallised PET capacitor, the unused spare for my 'Self' amplifier. At 8 watts output this capacitor generated -113.5dB third and -126.3dB fifth harmonic, distortions which would be reflected into the feedback network. Fig. 8.

Apart from this distortion, at 20kHz and 100 watts, this capacitor is subjected to more than twice the permitted sine wave rating for an Evox-Rifa MMK 0.1µF 63 volt metallised PET capacitor while almost any resistor easily manages the less than 2 volt and 0.6w R15 dissipates. To minimise distortion in normal use and survive no-load sine wave testing, the capacitor choice for this network is important. I prefer a foil and Polypropylene or Polyphenylene Sulphide capacitor.

Input capacitor C1

Many designs use an unbiased 10-22µF polar aluminium electrolytic capacitor, C1, to input the signal and block unwanted DC from entering the power amplifier, assuming that if sized to ensure minimal signal voltage across the capacitor at low frequency, low distortion is guaranteed. That may well be correct provided the capacitor is not subjected to DC bias. More than a few volts bias will result in second harmonic distortion which will be amplified.

I believe a polar aluminium electrolytic capacitor is false economy since quite small metallised PPS or PET capacitors are available. Polypropylene capacitors produce much lower distortion but are larger and expensive. An inexpensive bi-polar electrolytic is small and produces little distortion unless subject to significant DC bias voltage. For the best performance use a film capacitor.

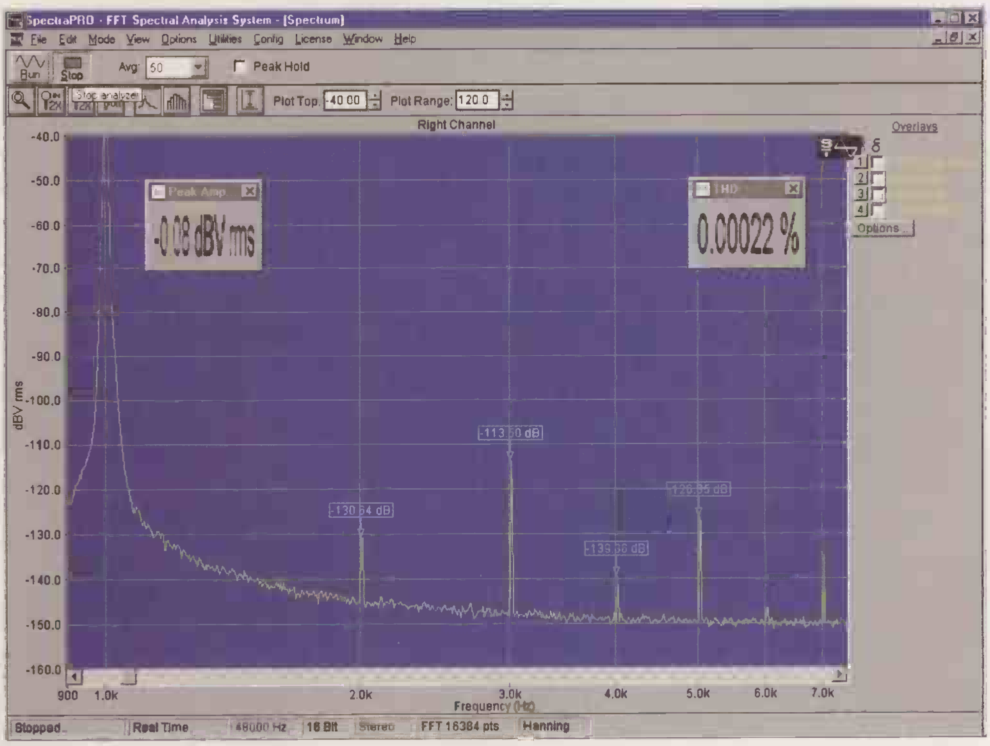
Class B bias stability networks

Many power amplifiers include another significant capacitor we should explore. Typically a 10-47µF is used to bypass the signal across the bias current stabilisation network. For values up to 22µF the lowest distortion most economic choice is a metallised PET style, closely followed by the 'double bi-polar' electrolytic capacitor[4]. For larger values, unless cost and size is no object, chose this electrolytic.

Many readers are familiar with the Douglas Self 'Blameless 50 watt class B' design, published in *Electronics World* February 1994. I have a pair, assembled on printed boards purchased from the magazine, which measured some 2.6 volts of DC bias voltage across their 47µF polar aluminium electrolytic capacitor C4, the bias current stabilisation network bypass capacitor.

Measurements of the AC voltage across C4, with the amplifier driven to 50 watts into 8Ω shows its AC voltage increasing significantly with frequency. At low frequencies, while the amplifier still has substantial open loop gain, this voltage remains small. As the amplifier open loop

Fig. 8. Actual measured distortion of the 'stacked' metallised PET capacitor in the Self Blameless 50 watt class B design, at 8 watts power in an 8Ω load. Distortion will increase rapidly with increasing power output.



gain reduces with increasing frequency, C4 is subjected to a significant signal voltage. At 10kHz I measured 1.15 volt AC using an AC coupled DVM to ignore the DC voltage. Any polar aluminium electrolytic capacitor subject to such AC voltage will generate very large second and third harmonic distortions.

The very best and quite expensive, specialist polar aluminium electrolytic capacitor of those I tested at 1 volt, generated some -93.2dB second and -100dB third harmonic with no bias. With 6 volt DC bias distortions increased dramatically, the second harmonic now -77.9dB. With 12 volt bias second harmonic increased tenfold to -72.9dB. Other polar aluminium electrolytics generated even more distortion when tested using a 1 volt signal.
The only cost effective, low distortion solution for this 1 volt signal level and DC bias voltage, is to use two double capacitance, 63 volt rated bi-polar aluminium electrolytic capacitors connected in series, the 'double bi-polar' configuration recommended in the last article of my first *Capacitor Sounds* series, *Electronics World* January 2003. Measured using 1 volt and no DC bias, this 'double bi-polar' capacitor combination measured -117dB second and -123dB third harmonic. With 6 volt bias, second harmonic became -102dB and -97.2dB biased to 12 volt DC as shown in this plot. An almost twenty times smaller distortion than measured using the best polar capacitor I tested, with or without bias. **Fig. 9**

Contrary to common belief, using an electrolytic well below its rated voltage does no harm, in fact it is beneficial, reducing leakage current, like choosing a more expensive, professionally rated, long life capacitor. Production electrolytic capacitors rated at 25-63 volt, provide better performance than lower and higher voltage types. In past years 'underunning' was frowned on because some badly designed electrolytes degraded the aluminium oxide dielectric. Subsequent application of rated voltage resulted in leakage current exceeding the maker's claim. Installed in circuit and underun for some time, a capacitor would not usually become subjected to rated voltage. Underunning never was a problem, rather a misunderstanding of capacitor and circuit behaviour.

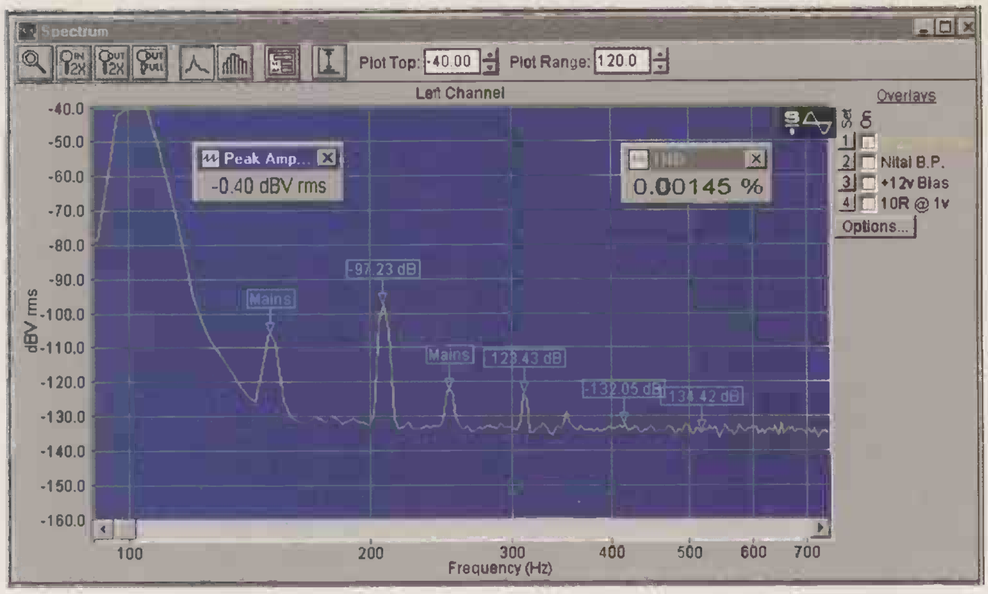


Fig. 9. Two 220μF 63 volt Nitai bi-polar capacitors in series made this 100μF "Double bi-polar" capacitor. Measured using a 1 volt AC and 12 volt DC bias as Figure 2, it generates almost twenty times less distortion. Second harmonic measured -101.75dB with 6 volt bias, -117dB unbiased.

Valve amplifiers

To date I have avoided discussing valve amplifiers because I do not possess one and so cannot make any confirming measurements. However, I believe the DC blocking AC signal coupling capacitor used between a valve anode and subsequent grid, subjected to large DC bias and AC signals, can create distortion.

I decided to measure a specialist metallised Polypropylene 1μF 630 volt MKP capacitor[5] and the 1μF paper capacitor reported in my August article, using a 6 volt test signal, the largest very low distortion signal I can generate across a 1μF capacitor using 100Ω source impedance, with DC bias from 0 to 100 volt, then compare the results.

The MKP capacitor performed as well as expected, second harmonic increasing from -132dB with no bias to -123dB with 100 volt DC bias, a superb result. In contrast the paper capacitor behaved rather less well, illustrating perhaps why second harmonic distortion often dominates a valve amplifier output.

With no DC bias, second harmonic of this paper capacitor measured -128.8dB but biased to 30 volts DC its -116.5dB second harmonic was worse than the MKP at 100 volts. Biased to 100 volts this paper capacitor performed badly, generating an enormous -108dB second harmonic. Third harmonic for both capacitors changed little with bias, staying close to -130dB. Second harmonic distortion for this and similar paper capacitors increases with DC bias or AC signal voltage. **Fig. 10.**

Power Rail Capacitors

The four polar electrolytic capacitors I exchanged for the bi-polar types included two 220μF power rail capacitors which are irretrievably linked with the power supply so cannot easily be evaluated in isolation. I plan to explore these as part of a future article.

In my next article, the last for this series, I measure distortions in low-level IC op-amp circuits and include a novel circuit technique that allows a modest op-amp to produce lower than usual distortion driving a low impedance load. In response to reader's requests, I also include a brief look at possible resistor and potentiometer distortions.

Conclusion

Having examined a variety of capacitor styles and their audio frequency distortions over the past two years, it is perhaps appropriate with the benefit of hindsight to summarise some findings.

For low level and pre-amplifier circuits but ignoring supply rail decoupling, most capacitors used will be small value and many will need

Table 3: AC and DC voltages measured on C4, with the amplifier set to generate 50 watts into 8R. This amplifier was assembled using printed circuit boards purchased from *Electronics World*.

Frequency	100Hz	1kHz	10kHz
DC bias volts	2.6v	2.6v	2.6v
AC signal voltage	0.095v	0.158v	1.15v

FFT Software

Throughout my *Capacitor Sounds* series except the first two articles, I used the SpectraPlus232 software for my distortion plots. This software is easy to set up and has served well. However some readers have asked whether lower cost software might be used, since a full set of options can become expensive.

I have now found two alternatives. Provided the reader can accept not having the on screen THD% display, all other facilities I used are provided by purchasing only the Spectra base module, almost halving the cost. The on screen THD% option can be purchased later.

My second alternative is 'WinAudioMLS Pro', I evaluated version 1.66, a new version having its microphone correction ability updated for use with my test equipment, or a conventional microphone. It can be obtained from the Dr. Jordan web site.

As standard this software provides a THD+N display and cursor controlled readout of harmonic levels. It accepts the microphone correction file, essential when using my notch filter/preamplifier assembly. In addition to all the features needed for my measurements it also provides an MLS measuring facility. This can be used to measure loudspeaker and room responses as well as the impedance and phase of low impedance components, especially those used in loudspeakers. All this for less cost than for the basic SpectraPlus232 module, makes this software well worth your evaluation.

This software also has a range of additional upgrade options, but I found the base WinAudioMLS Pro version with their THD% option, sufficient for my needs.

Contact
WinAudioMLS Pro
http://www.dr-jordan-design.de
SpectraPlus232
http://www.soundtechnology.com

1% tolerance. For values up to 47nF we have a choice of near perfect, very low distortion, extended foil and Polystyrene or extended foil and Polypropylene capacitors, available at 1% in both axial lead and 'tombstone' styles. COG ceramic capacitors at 5% tolerance, as low cost discs for small values and multi-layer capacitors to 100nF, are distributor items. Larger capacitance values and closer tolerances are manufactured. COG ceramic provides low distortion, unsurpassed capacitance stability with voltage, temperature, time and frequency, the almost perfect capacitor.

For values of 100nF and above, we could use multiples of the above types but foil and Polypropylene styles are available to 10μF, regardless of DC bias they assure very low distortion. Metallised PPS types produce little distortion unless subject to significant DC bias. Available to 10μF and 1% tolerance, PPS capacitors provide excellent temperature and long-term capacitance stability in smaller case sizes than Polypropylene types.

Power amplifiers needing larger value signal path capacitors, should use bi-polar aluminium electrolytic capacitors, avoiding the conventional polar aluminium electrolytic capacitor for audio signals. With signal voltages across a large capacitor of 0.5 or more volts, the 'double bi-polar' aluminium electrolytic capacitor, two double value conventional bi-polar aluminium electrolytic capacitors in series, is demonstrably the most economic low distortion choice. Many writers advocate using lesser value film capacitors, to bypass a polar aluminium electrolytic capacitor to reduce its distortion. My measurements show this has little effect, compared to using the bi-polar style, which produces much lower distortion at less cost.

Distributor stocks of bi-polar aluminium electrolytic capacitors rarely exceed some 470-1000μF at low voltage, this results from customer demand and not capacitor technology, manufacturers will respond to market demand as will distributor stockholdings.

More than 30 years ago I developed a range of bi-polar or *reversible* electrolytic capacitors up to 10,000μF at 63 volt and the Erie Company manufactured many thousands. The largest example which I still have today, a 2,000μF 100 volt in a 115 x 45mm case, was developed as the output coupling capacitor for a very high power audio amplifier. ■

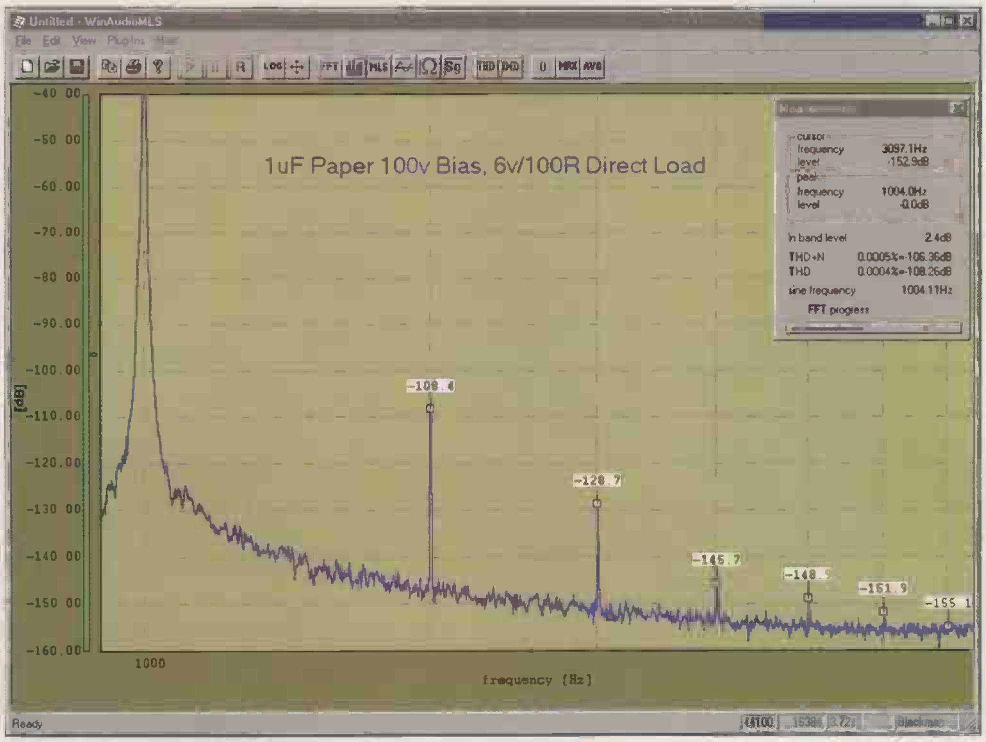


Fig. 10. A typical 1μF paper capacitor, with 6 volts AC at 1kHz and 100 volt DC bias, produced this excessively large second harmonic distortion. The 630 volt 1μF MKP Polypropylene capacitor was five times better with second harmonic -123dB, third -130dB, just 0.00008% distortion. This plot was measured using the Dr.Jordan software, the SpectraPlus232 gave almost identical results.

References

1. Capacitor SoundsII. C. Bateman. *Electronics World*, October 2003.
2. Capacitor Sounds. C. Bateman. *Electronics World*, July, September 02, through January 03
3. Understanding Capacitors - Electrolytics. *Electronics World*, June 1998.
4. Double bi-polar aluminium electrolytic capacitor. *Electronics World*, January 2003. Patent application GB 0227606
5. Audio-Grade Polypropylene axial capacitor. Maplin Electronics part no. KR78K.

LETTERS to the editor

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

Historic receivers

I was reading the article by Jeremy Stevens on 'Receivers of the Third Reich', which I found most interesting, but the marking of the capacitors reminded me of a similar situation in British military radio history.

Many years ago, I was employed by a TV sales and service company owned by an ex-army (probably REME) officer who had served in WW2. He loaned me some books entitled "Handbook of Wireless Telegraphy", the Admiralty Radio Handbook, published by HMSO in 1938. These tombs covered every detail of technology at the time, in fascinating detail.

The thing which sticks in my mind the most is that all capacitor values (or condensers, as the term was then) were given in 'jars'. Somewhere there was a note explaining that "the jar is now obsolete as the service unit, having been replaced by the Farad and sub-multiples thereof." Despite this statement, all the worked examples are done in terms of jars! Fortunately a colleague has the same manuals, and has loaned them to me to do this little piece of research.

The jar, based on early capacitors built in 'standard' Leyden jars was equivalent to 1000cm. It goes on to give conversion factors to and from micro-Farads where $1\mu F = 900$ jars[1]. The same paragraph states that a cm (centimetre, yes really) is that value of capacitor which when charged with 1 Electro Static Unit of charge, has a potential of 1 ESU of PD (voltage) between its plates. Further references define the ESU for charge and ESU potential difference.

Charge is defined in terms of force in dynes exerted between two unit charges at 1cm distance in *vacuo*. This evaluates as1 coulomb = 3×10^9 ESU. The ESU[2] of PD is defined in terms of coulombs and ergs, and evaluates to 300volts[3].

For the younger reader, the Leyden jar is a bit like a square glass jam-jar with a lift out metal centre and a metalised outer shell. The unit can be charged, separated, handled, then re-assembled and discharged. The only time I have ever seen one was in my physics lessons at school, where the thing was charged from a Van-der-Graaf generator, duly dismantled (using a long, insulated rod) and played with by the whole class, ultimately to be re-assembled and then discharged with an impressive 'crack'.

It was used to clearly demonstrate that the charge was stored in the dielectric, in this case, the glass. The metal parts from a fully discharged jar were then assembled around a previously charged and dismantled glass jar, with the same satisfying result.

Following on from the great EMC debate, most of us appreciate the thinking behind the CE marking of electronic equipment, but it is ludicrous to try to implement the regulations imposed in the manner that they have been. With so many loopholes and escape clauses, a carefully worded paragraph in the CE statement will let most things off the hook.

The tests applied can be quite selective. For example, electrically a kettle has a resistive element, is unlikely to be susceptible to RF emissions (short of a nuclear explosion) and providing that the switch has some spike suppression, is unlikely to emit much radiation. Is this device justified in being subjected to a full product spec EMC test similar to that for a complex multi-way fire alarm system?

Similar reasoning can be applied for a 'likely use' aspect of a piece of equipment. A simple battery and bulb torch may carry a CE mark. If one were to build a similar torch, but using an inverter and white LEDs, should this have the same or a more stringent test applied? These decisions are left to the manufacturer, but if we get it wrong what then? Fines, confiscation of equipment, each director held singly and jointly at fault. What a minefield!

The great CE con is in full swing

1000 lines, Green

Leslie Green's article on Calculus was well written. The answers had 3 typos.
(1) answer 1 is 26.66 V / microsecond
(2) head of answer 3) missing
(3) answer 4) mean power in resistor is 25.75 W

George Barnes
Hunter Institute
Newcastle TAFE
Australia

Green II

Leslie Green's article on basic maths is admirable. Perhaps someone should likewise take up cudgels on behalf of logarithms. It's quite amazing (to the calculator-bound majority) what can be done with mental arithmetic and logarithms.

I should like, if I may, to propose a small clarification. 'RMS power' is of course calculable but is, as the article states, neither valid nor useful. What's invariably meant is quite simply average power. Voltage or current is measured as Root Mean Square and is then squared in the process of calculating power. 'Root mean' squared becomes simply mean, a.k.a. arithmetic average. I suspect that to most of us plain 'average' simply sounds instinctively too vague, accurate thought it may be!

Re: Catt etc., please keep this stuff coming. It clearly makes a lot of us think and that's no bad thing! But could letter-writers on audio please read Doug Self's articles (or books) before armchair theorising? Usual disclaimers - I've never met him etc. etc. - but he's already invented the wheel and credit to him for telling us exactly how.

Richard Black
London
UK

now. Have you found a piece of equipment with a mains lead attached lately? It would appear that if the unit radiates undesirable RF signals from the lead, then technically it fails the EMC emissions test. On the other hand, if the lead can be unplugged, and the lead is CE marked (and most mains leads are fairly benign when not plugged in or connected only to a resistive load after all) then they are classed as separate items, and the unit with no lead can be certified. Hence the rise in equipment supplied with 'kettle' leads. Of course, having connected them together and switched on the unit, does the whole assembly fail to comply, and who could be held responsible for any undue emissions? Both the device and lead are CE marked and therefore can be supplied legally, but who is at fault - the customer? "I know nuffink, Guv! That's how it came in the box!"

Similar reasoning is applied to 'plug top' power supplies. On its own, the PSU passes the relevant tests for its class of equipment. Similarly, on its own, the powered equipment passes, except for radiation from the power lead. So: fit a DC socket and CE label, and supply a CE marked PSU. Job done!

Perhaps the faceless men in Brussels should stick to defining the size of the Euro-apple, or the colour of the standard Euro-tomato, or even the shape of the standard Euro-car, and let our industry do what it does best - make working, reliable products with minimal interference radiation and absorption problems.

After all is said and done, Joe Public will let us know, for certain, that his new video, TV, computer, radio etc. does not work, so we have to design in interference suppression anyway.

As for EMC susceptibility, again J.P. will avoid the radio that he has heard will only receive Radio 2 LW if it is in a steel shed down the garden!

References taken from "Handbook of Wireless Telegraphy Volume 1" published by HMSO 1938
paragraph. 167
paragraph. 95
paragraph. 102

Andrew Denham
By email

More history

I thoroughly enjoyed reading the well researched and illustrated historical article in the August 2003 *EW* issue on the VE301 valve radio receivers of the Third Reich. It is revealing to look back at the often elegant techniques used to solve design problems despite the limitations of the components available at the time. What is also striking is that the valve design goals where achieved with a very low component count - size and cost prevented 'Norwegian coast' designs (apologies to the late D. Adams!).

The nostalgic days of World War II were well before my time. I passed my formative years in the transition from valve to semiconductor technology in the 1960's and remember well the problems these fragile germanium newcomers provoked - do you remember the OC series ?!! It is amusing now to look at such details as the influence of valve chassis design culture on the early attempts at portable transistor radios, each stage often being an isolated island of components as if there was a phantom valve base. Compare that to a smd digital pcb of today!

There is much wealth and wisdom in the fascinating legacy of a century of electronics development. The scope for further historical articles drawn from this heritage can only be limited by your enthusiasm to print them, so please, more of that kind of thing!

Peter Sullivan
Geneva
Switzerland

I am actively looking at doing some more historical articles as it has proved very popular. Watch this space, and yes I remember them well! – Ed.

Content and Focus

I have been reading *WWW, E & WW* and now *EW* as my magazine of choice since 1957 and have seen many changes in its presentation and content! Normally I'm one of the silent majority, but now feel the need to comment on this apparently vexatious matter. My latest copy is July due to normal subscription delays to NZ, so I hope that my comments are still appropriate.

Whilst I accept that change is constant and that any magazine, journal or periodical must adapt to survive, there are, I submit, some notable aspects that must never be seen as compromised. These would include technical accuracy and timeliness. Two areas that *EW* seems to handle well I think. There also, seems to be a fair balance between non-computer based and computer based articles or those with a high degree of academy. If there's a lacking in any way, for me, it would be in the areas of 'High End' projects, especially those of the calibre of Cyril Bateman's "Capacitor Sound", or Doug Self's Audio projects and J.L. Hood's work.

An area that *EW* can serve well is to support solid discussion on the many contentious issues often given only a relatively fleeting coverage in Letters. With the many skilled writers and contributors at the disposal of *EW*, I could imagine some lively, interesting and engrossing articles. There is no other technical journal that does this that I know of.

Looking back and doing a brief check of my library, between 1957 and when *WW* became *E&WW*, the things most evident were its thickness and the relatively constant proportionality of articles to total pages along with the preponderance all thing British. In 1978 there were 128 pages and 44 of them were technical, in 1986 perhaps the publisher was hard up as it only had 96 pages and a similar proportion of technical, and in more recent times 2002 there were 55 pages of which 25 were technical. The other notable aspect is the value for money - this appears not to have markedly changed in relation to technical content. Say 40 pages for £2.95, which equates well to the costs of living during the past 20 years or so - in May 1981 it was 60 pence. Also noteworthy in terms of value for money is my current issue (July) of the journal, for of its 64 pages, no less than 40 are technical if you count the letters! Value increased?

However, looking back again over that period, there seems not to be any replacements for regular small feature writers like 'Vector', 'Cathode Ray' and SW Amos or indeed the Lab Technician/projects manager. I note that many technical magazines have their own Lab and most have articles written from, or at least verified from their specific labs. Perhaps *EW*'s lab would have a lot to do with proving some of the letter discussions as mentioned. It could also enhance the credibility of some projects and become a reference point for those seeking advice on a project.

One of the dangers of change from a readership point of view, might be evident if the journal were to become too market oriented, by having larger numbers of advertisements or become a medium for specialised promoters like test gear manufacturers. For me, the current exposure of such material is now borderline. I know it helps to pay the bills, but we the readers, should not have that foisted upon us simply because of costs. I would be one of those who would approve an increased subscription rather than see the magazine degrade in that way. As an aside to this issue, are there any possibilities of any kind of relatively neutral technical sponsorship?

There would I suggest, be a quite a large readership who read this Journal, purely for its technical content and detailed approach without ever making a project, often using it to keep up to date by, or as reference. For these readers the broadest technical content will always be welcomed and to limit it by concentrating on what is purely vogue or topical might not be useful.

In general, I applaud *EW* for its breadth and depth and hope that it will continue to maintain its standards and even improve upon them with a resident Laboratory and Manager.

Terry Bicknell
Waikanae
New Zealand

Glass Houses

I would not judge Alan Bate MIEE as suitably qualified to comment on the contributions of others (Letters, *EW*, September 2003). I base this judgement on his description of a simple(sic) two-gate latch. He explains its operation using three statements - and all three are wrong. The latch (as drawn) does not set at power up - it resets. The latch does not change state as soon as contact A momentarily opens - it changes state when contact B momentarily closes. The latch has not already set by the time the switch pole is contacting B - it is still reset.

In the same issue R Harris concludes his(?) letter berating *Electronics World* for '... rather sloppy English ...' (citing a recent spelling error). However, his previous paragraph ends with a far worse example of sloppy English - '... any potential contributors out there.' The grammar is passable but the word 'potential' makes no sense at all, the correct word is 'prospective'. This is because we are all potential contributors by virtue of being able to write in English but, since most of us are insufficiently informed on the subject matter, we would first require a considerable period of study, so few of are prospective contributors.

I don't object to criticism but I do think that it should be properly informed.

Richard Burfoot
Yate
Bristol
UK

Automotive audio systems

I have enjoyed very much Mr. Catt returns in March issue and that *Electronics World* is appealing. Not a subscriber as yet but a buyer at the bookstand. When is the time that some writers will contribute to the automotive audio systems? The in-car-entertainment; manufacturer basics, like DIN connectors used and to interface such a task. Computer has so much learning criterion than I will see in automotive audio system. In bookstores are many computer books than any other books on the stand. Where is auto audio? Thank you for the great work.

Tony Neiburg
St. Paul
Minnesota
US

Sounds like a gauntlet being thrown down to me - Ed

De-bounce II

With reference to Alan Bate's comments on Deng Yong's switch de-bouncing circuit (Letters, September 2003), would it be stating the obvious to point out that Mr Yong's circuit will work with a simple ON/OFF switch, whereas the standard bistable circuit requires a two-way switch? The more complex circuit would be useful when adding-on circuitry to an existing piece of equipment, or in situations where a two-way switch is not feasible.

Ronald Ogilvie
Killearn
Stirlingshire
UK

Design for EMC

In his letter "Student knowledge and EMC" (*EW* Sept. 03), Cyril Bateman identifies one of the most significant sources of interference - EMC filters. These devices are designed to reflect unwanted energy back into the conductors. Since this energy is not dissipated in the conductor resistance, it radiates into the environment and reappears as unwanted interference. The culprit circuit may be immune, but what about other equipment in the vicinity of the supply line?

Mr. Bateman treats the topics of 'student knowledge' and 'EMC' as two entirely separate issues; thereby highlighting the fact that no one really expects young graduates to have any useful knowledge of electromagnetic compatibility. It is assumed that such knowledge can only be gained the hard way - through experience.

This situation exists in spite of the need for a clear understanding of the phenomena by anyone who designs or uses electronic equipment. If no one is provided with the basic analytical tools when they are introduced to the subject, then very few are likely to discover those tools for themselves when faced with a real problem, especially when the budget is tight and the timescale is limited.

The young engineer is confronted with a virtual mountain of literature on the subject of EMC and is all too easy a prey for those who provide courses and seminars of dubious value at extortionate prices. The result is a sense of extreme frustration. Ivor Catt indicated this in his article in the March 03 issue of *EW*.

Bateman in error - shock

Your current EMC debate is unlikely to resolve satisfactorily when even (respected) Cyril Bateman seems to be in error. In his letter of your September issue he states, "An EMC filter in contrast, while it may still produce 50dB attenuation, dissipates almost no energy." Well, no, actually. A correctly designed EMC filter absorbs energy with a frequency proportionality inherent of ferrite loss characteristics, and after ferrimagnetic resonance the impedance becomes ostensibly resistive. Check out 'Ferroxcube' (now Yageo apparently) publications for elucidation. Of course pure reactance can play a part whereby the energy is reflected back to from whence it came, hopefully a sealed unit, but this is a very dangerous practice upon which to rely. My July 2001 article "Elastic Capacitors" alludes to the pitfall, as does Cyril, of the dubious practice of slapping in inductors in the blind belief that it will probably help.

The efficacy of the absorption is easily demonstrated. For instance, many years ago I designed a switcher of only a few watts and cleaned the spikes with a ferrite bead. It got reasonably warm. On a more recent 60 watt design, I burned a finger tip on an inappropriately selected filter ferrite when searching for what was smelling, and no it wasn't copper loss.

Regarding Cyril's appraisal of domestic washing machines having included EMC filter solutions for the last 30 years, I don't think my last machine was aware of this. My scope protested audibly when the thyristor spike generator kicked in. Could have fried pies on the radiation.

A S Robertson
Girvan
Ayrshire
Scotland

The nub of the problem is the fact that EMC requirements are not subjected to a rigorous analytical process; in sharp contrast to other design requirements such as system function, response time, stability, power consumption, reliability, mass, size and cost. Admittedly, there are useful hints, tips, and fixes to be found in some books on the market. But such advice can hardly be classed as analytical.

However, it is not particularly difficult to create a circuit model of the configuration under review, analyse the electromagnetic coupling between independent circuits, and validate the results using simple bench tests. When the coupling mechanism is understood, it can be controlled.

Such an approach was introduced to readers of *Electronics World* in the August 1998 issue by the article 'Grounding on a different plane', and developed in subsequent articles. For those who have no time

Errors, nonsense and 'The Question'

It's not only my handwriting that gives rise to errors. John Barrow explained in his article 'Glitch' (*New Scientist*, 7th June 03) that superior intelligences in a multiverse model – an extension of DeWitt's 'many worlds' interpretation (1973) are not immune from this phenomenon. Not only are they inevitable; they are necessary: for economical reasons (in terms of computing resources needed) and for survival (IGUS Information Gathering and Utilising System, Gell-Mann and Hartle, 1989). Paul Davies believes that "our living in a fake, simulated reality is a nonsense", although the model is popular with many theorists.

If qPCs (quantum personal computers) become available we won't even need to switch them on – or buy them! Whether or not we'll need VDU/WP/email with this set-up is beyond my ken. Perhaps Ivor could explain?

Sébastien's observation that "0.5% distortion is more appealing than (nearly) none at all" is something to think about, especially when you consider all the time and effort that has been devoted to eliminating it!

When you wrote that you "will draw a line under the EMC debate" at the end of Ivor's letter about the Catt Anomaly, I got a bit confused! No big deal.

The EMC debate has had a good airing and probably deserves a rest, but the same can't be said of the 'Catt Anomaly' which may be closely associated with one of the strangest problems that has cropped up in theoretical analysis to date, that is: - time reversal, or 'time runs backwards'. Martin Gardener has tackled this problem in his latest book "Are Universes thicker than blackberries?"

The idea stems from the work of Kornhuber (1976) and Libet (1979), which Roger Penrose discusses (at the end of his books) in conjunction with consciousness and language. The main findings are that (i), a and individual's brain response precedes a stimulus; and (ii), there is a 'dead time' of about 0.5 second. Little or no mention has been made to the relationship between 0.5s and 2Hz – except in *EW*! The findings of brain research – in some cases, using electrical probes – was summarised by Susan Greenfield in *The Mind Game* (BBC 2 TV) in 2002: -

(i) time runs backwards
(ii) all history is pre-recorded in the brain
(iii)the brain samples the record at intervals to create a sense of time, objective or whatever?

These ideas are not new! (vide refs 2,4)

One of the most exciting developments comes from the findings of Vitor Ramachhandran, who appeared in *The Mind Game*. In the last of the *Reith Lectures* (BBC Radio 4) for 2003, he suggested that "the origin of cognition lies in the sounds found in the language centre of the parietal lobe.... and probably, quite a small number". Curtius listed 664 basic phonemes (roots and stems) of which 17.3% involve Kappa and most conform to Zipf's law and Shannon's Eutropic order for intelligent interaction. 'Kai' is the locative pronoun from the Skt. 'kas', still used in Cyprus, which lends itself to the Latin 'que' (kwā); Italian lost the 'w' whilst German and English lost the 'k'.

Tracing 'kai', 'su' and 'tu' to its roots is easy – 'Bruton' (fermented wine) is more involved. If it's from Sanskrit 'brahm', by loss of aspirate (h), it should have carried the meaning 'whirring whirling motion' rather than 'whirring sound' or 'breath'. Hebrew, however, uses HeBeL and HeVeL for 'whirring whirling motion' in Ecclesiastes 1:2 "Vanity of vanities... all is vanity" (KJ), but retains 'h' in BaHiR (Job 37:21) for 'bright light'. Sanskrit 'ruk' (light) softened in Greek to 'luk' and further in Italian to 'luce', but is retained in 'ēlĕcktron' (amber, shining metal), although Curius associated a different provenance! Why?

One reason might be the mechanism which Rama' described: leakage from the parietal areas into other sensory and brain areas (synaesthesia), as for example, in the case of 'The man who couldn't tell the difference between his wife and his hat' (Oliver Sachs patient). The leakage might be quite common, however, even in 'normal' people! – including physicists. If this mechanism is coupled with the 'many-minds interpretation' of Everett, elaborated by David Deutsch (in 1985) in a bifurcating model, as against the many worlds interpretation of DeWitt (multiverses), which Paul Davis thinks is nonsense, it's possible to see how the contradictions in modern physics may be resolved. This will create problems, however, for electronics theory where frequency and time are inversely related in standard models, which brain researchers assume! In bifurcating brain processes, period doubling is 'perceived' as frequency doubling. This *is* 'real time'.

To a certain extent, the reasoning in 'The Question' and in Nigel Cook's articles (*The Electronic Universe*) about 'awareness' of an open circuit are soundly based – it's not nonsense. Electrons, photons, beables (John Bell's), Hu particles *are* aware. That's what many leading physicists believe. David Bolm and Basil Hiley discuss this in 'The Undivided Universe', Routledge, (1993) in chapters 13, 14 and 15.

Lit

1 George Curtius *Principles of Greek Etymology*, 5th edition, 2 vols English translation, A.S. Wilkins, E.B. England, Pub.: John Murray, London.
2 Gershom Scholem, *Origins of the Kaballah* (1962), English translation (1987) Princeton University Press, Ch 2 *The Book BaHir*.
3 David Bohm and Basil J. Hiley *The Undivided Universe, An ontological interpretation of quantum thoery*, Pub: Routledge, (1993), London.
4 John Berges *Hidden Foundations of the Great Invocation*, Pub: Planetwork, NJ, USA.

G3OMD
***Tony Callegari** BSc., MPHIL., (Lond)*
Much Hadham
Hertfordshire
UK

A model handwritten letter complete with an 'error code' column! My wife much appreciated it! – Ed.

to go hunting for back issues, the information is available at the website www.designemc.info.

The suggestion that any EMC problem could be analysed by any electronics engineer will be greeted with extreme scepticism; especially by those who have been steeped in the propaganda that it is an arcane subject whose secrets are available only to the gifted few. However, anyone who overcomes this scepticism will be able to visit the site. It contains an e-mail address for any comment.

Ian Darney
Kingswood
Bristol
UK

Google search

Ivor Catt suggested (*EW* Sept 2003 p.57) a Google search on "Pepper FRS". I did this and am pleased to have taken his advice; I spent the next three days virtually glued to my screen! Incredible stuff.

Charles Coultas
Wokingham
Berkshire

Self replies

In answer to William C. Cross' letter last month - if I understand this suggestion correctly, it could indeed be set up to make the input FET drains track the gates and so render non-linear capacitance here innocuous. This does however still leave you with the greater non-linearity of a FET input stage to grapple with, plus the need to use expensive dual devices to cope with the input offset voltages.

Douglas Self
London
UK

Meaningless algebra

I must apologise that until now I have not had time to respond to Mr. Koren's letter published in the August *EW*.

That someone can dismiss algebra as 'meaningless' needs no observation from me but Mr. Koren's misunderstanding regarding experimental error does need comment. Since he has declared his algebraic scepticism, let us work in the numeric field.

Suppose a Wheatstone Bridge uses all 1% resistors and in a particular job is balanced at 4321 ohms. At most this value could be 4364.21, an inflation of 43.21 ohms. Of this the error in the thousands is 40, in the hundreds is 3, in the tens is 0.2 and the units contribute 0.01.

However, if only 10% resistors can be found for use in the units decade, the 1 ohm resistor could have a maximum value of 1.1, which would now contribute 0.1 ohms to the total of 4364.3. Thus the overall accuracy would change from 1% to a maximum percentage error of 1.002%, i.e. practically no change at all. Consequently there is *every* reason to have high specification resistors in the upper decades while lower tolerance components can be used in the units decade since they will contribute less significantly to errors overall.

It is with this in mind that manufacturers of test gear which use digit displays often declare their equipment to be '1% accurate, plus or minus one digit'.

The only time that using10% resistors in the units decade would be significant is when the bridge is balanced at 000X (X between 1 and 9) but this would represent poor use of the divide-by-1000 facility designed as part of the bridge circuit in the published article.

David Ponting
Clutton
Bristol UK

Understanding ADCs

I am referring to the article "Understanding inputs to ADCs" by Mr. Daniel Malik in the June 2003 issue.

In the example given of the change in potential (voltage) when a 5pF charged condenser (capacitor) is connected in parallel with a discharged 0.5pF. It is stated that the potential will drop to 95% of its original value.

My calculations below disagree. Assuming the condenser was originally charged to 1V.

Ct+Cp=5pF (charged to U=1V)
Cx=0.5pF (discharged, connected in parallel)
Q=U*C Q=5e-12 C (original and final total charge)
U'=Q/Ct+Cp+Cx U'=5e-12/5.5e-12 U'=0.91V (final potential)

Also it is stated that 1/2(Ct+Cp)*Uin^2=1/2(Ct+Cp+Cx)*U'^2. This implies that the energy is preserved after connecting the charged and discharged condensers in parallel. To the best of my knowledge, this not so.

I have not read the whole article, so I cannot comment any further.

George Nole
Wytaliba NSW Australia

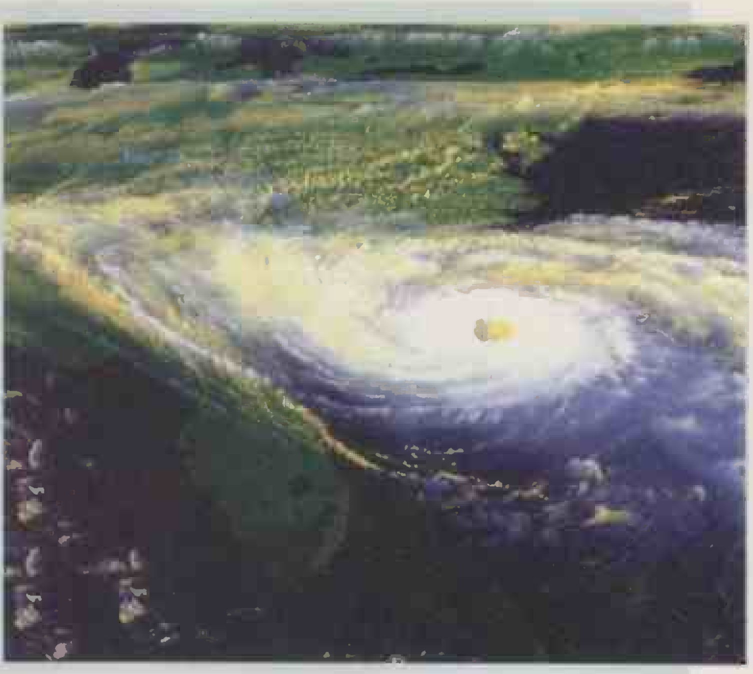
July cover

No doubt you have been asked this many times, but I haven't spotted any reference.

What is the location of the spectacular storm photo (cover and inside article) in the July issue?

Alan Watling
Colchester
Essex
UK

Unfortunately, the image came from a generic picture CD that did not have any info as to the whereabouts of the satellite –Ed



TIME MACHINE

Accurate time measurement on a budget by John Morrison

When trying to calibrate a watch or any other device that produces a one cycle per second pulse it becomes very difficult, if not impossible, to measure and adjust using standard 'off the shelf' equipment. The oscilloscope is of no use as the graticule spacing resolution is unreadable when trying to calibrate to 0.001 of a second in the 0.2 – 0.5 scale. A similar problem occurs with the frequency meter, as frequencies below 10Hz cannot normally be measured.

However it is possible to make a low cost unit that can measure 1Hz to a resolution of 1000th of a second.

Measurement basics

If the pulse to be measured is used to turn a fixed frequency count on then off at, for example, 2000cps, then the count available at the end of one second should be 2000.

If the pulse to be measured produces a count that is above or below the 2000 expected - then the pulse is either slower or faster than one second. Note: a slow pulse will give a number greater than 2000.

By using a homemade pick-up coil and an op amp, pulses can be detected from most quartz clocks that have hands. These clocks operate by pulsing a small solenoid at one-second intervals.

The pulse to be measured may not be an exact square wave, as in the clock example, so the unit must take this into account.

The pulse width shown in Fig 1(B) is 1 second overall, but looks very different to A.

To measure the counter is cleared every time the pulse goes low. There is no stop counter.

Some sort of display is required to show the results of the measurement. Using a 4-digit display would be overkill. A 10 segment Bar graph display is cheaper and produces an easier to understand readout.

The unit could be produced using several discrete devices including decimal counters, and IC gates but a better way is to replace most of these with just one microcontroller. The other advantage with this approach is that any frequency can be measured with extreme accuracy, simply by changing the software.

Micro-controller

There are many cheap micro-controllers on the market. This design needs one that can drive LEDs directly, has an internal timer and a prescaler. The one chosen meets this specification, a Microchip 16F84. This controller also has re-programmable code memory and is cheap and readily available.

If you have never worked with micro-controllers, this is an ideal choice as there is a huge amount of information and examples on the microchip website www.microchip.com

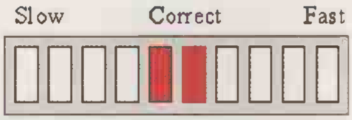


Fig. 2. 10 segment bar graph display.

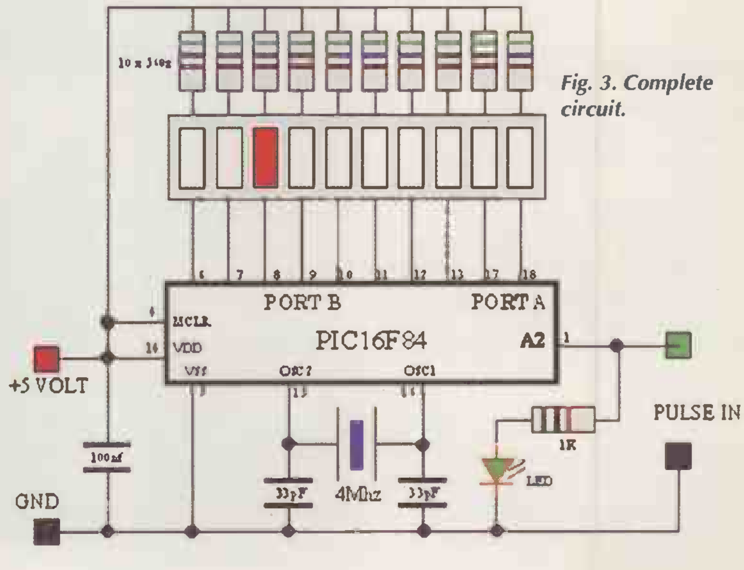


Fig. 3. Complete circuit.

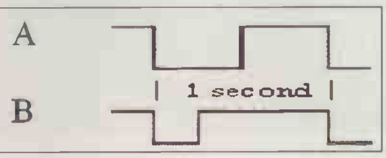


Fig. 1. Pulse width comparison

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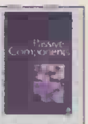

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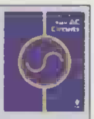

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Douglas Self

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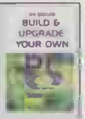

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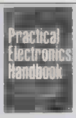

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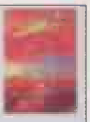

Trevor Wilmshurst

Aimed at junior undergraduates, this textbook offers comprehensive coverage of analogue electronic circuit design with two full chapters devoted to the use of SPICE in circuit simulations. programmes leading to IEng MSc Electronic conversion type courses.

Mar 2001 ▲ 320 pages ▲ PB

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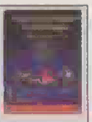

Jon Varteresian

Engineers are often faced with the need for small quantities of a certain board design for construction of a small number of devices. This book describes the process of making a printed circuit board, from the conversion of a schematic diagram into a board layout to the making of the board itself.

Jul 2002 ▲ 251 pages ▲ PB

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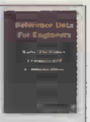
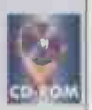


Mac E Van Valkenburg

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



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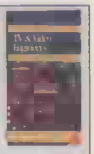

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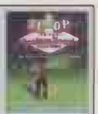

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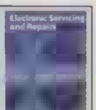

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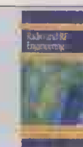

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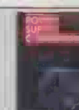

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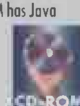

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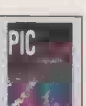

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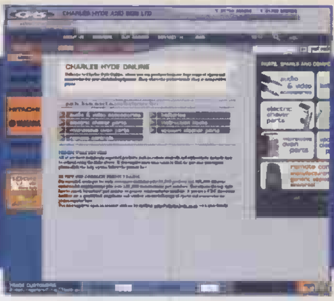

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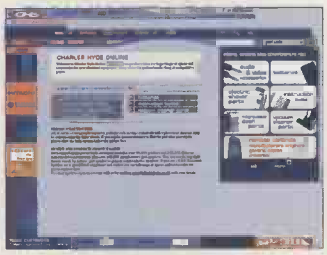

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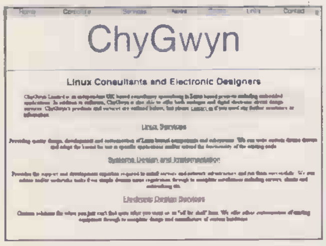

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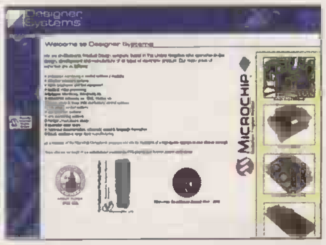

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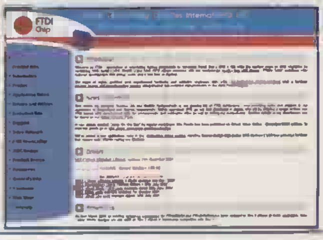

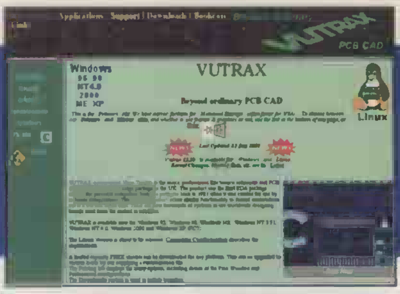

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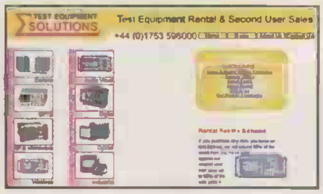

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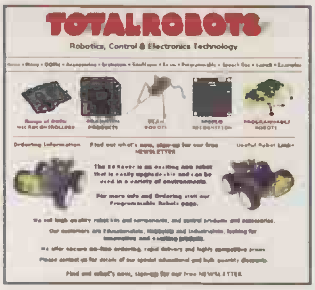

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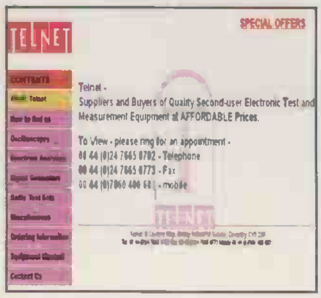

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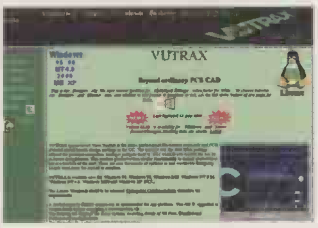

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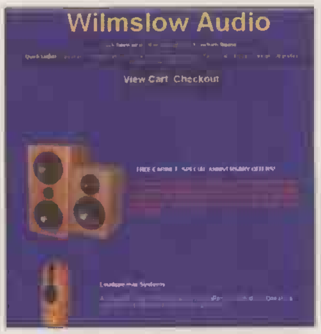

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