DIY MFB loudspeaker

Budget T&M on a PC

VI protection in power amps

Capacitor sound part 3

Circuit ideas:
Speaking clock

Novel combination lock

CAD on a shoestring
Quality second-user test & measurement equipment

Radio Communications Test Sets

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anritsu MT 8601C Radio Comms Analyser 300kHz - 9GHz</td>
<td>£4,470</td>
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<tr>
<td>Hewlett Packard 3620B (opt 4,7,11,12)</td>
<td>£6,750</td>
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<td>Marconi 2955</td>
<td>£1,250</td>
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<td>Marconi 2955A</td>
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<tr>
<td>Marconi 2955B/R</td>
<td>£3,500</td>
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<tr>
<td>Marconi 2955R</td>
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<tr>
<td>Racal 6111 (GSM)</td>
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<tr>
<td>Racal 6111 (GSM)</td>
<td>£1,750</td>
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<tr>
<td>Rohde &amp; Schwarz CD 57 GSM test set (opt B1/64/7/19/42/43/61)</td>
<td>£9,795</td>
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<tr>
<td>Rohde &amp; Schwarz CM 90 (2GHz) DECT</td>
<td>£3,995</td>
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<tr>
<td>Rohde &amp; Schwarz CMTA 94 (GSM)</td>
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<td>Schlumberger Stabilock 4303</td>
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<td>Schlumberger Stabilock 4400</td>
<td>£1,300</td>
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<tr>
<td>Wavelet 4103 (GSM 900) Mobile phone tester</td>
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<tr>
<td>Wavelet 4106 (GSM 900, 1800, 1900) Mobile phone tester</td>
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Oscilloscopes

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<tr>
<th>Model</th>
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<tr>
<td>Tektronix TDS 104</td>
<td>50MHz Dual Channel Oscilloscope</td>
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<tr>
<td>Tektronix TDS 204</td>
<td>100MHz Dual Channel Oscilloscope</td>
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<tr>
<td>Tektronix TDS 304</td>
<td>200MHz Dual Channel Oscilloscope</td>
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Spectrum analysers

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<tr>
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<tr>
<td>Advantest R3124</td>
<td>40MHz Dual Channel Spectrum Analyser</td>
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<tr>
<td>Tektronix TDS 306</td>
<td>50MHz Dual Channel Spectrum Analyser</td>
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Miscellaneous

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<td>Tektronix TDS 204</td>
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<td>Tektronix TDS 304</td>
<td>200MHz Dual Channel Spectrum Analyser</td>
<td>£3,950</td>
</tr>
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</table>

All equipment is used - with 30 days guarantee and 90 days in some cases. Add carriage and VAT at all goods.

Telnet, 8 Cavans Way, Binley Industrial Estate, Coventry CV3 2SF.
COMMENT
More enthusiastic readers

NEWS
- Matlab gets speed boost
- Pollution free South Wales
- Nanotubes-to-go
- valve boosts PC sound

LETTERS
- Storm Scope
- EMC
- Spring conundrum
- Your thoughts
- Circuit idea re-visited
- Scroggie help
- Spellign or Grammer?
- Double sided PCBs
- MOSFET compensation

CIRCUIT IDEAS
- Experimenter’s pendulum timer
- Speaking clock
- Telephone in use indicator
- Novel electronic combination lock
- Accurate voltage to current converter
- CAD on a shoestring

NEW PRODUCTS
The month’s top new products.

TYING THE KNOT
The concluding part of the motion feedback project

TRANSPARENT V-I PROTECTION IN AUDIO POWER AMPLIFIERS
The desirability or lack thereof, of over-voltage and over-current protection for power semiconductors in audio power amplifiers remains a point of contention in the field.

WEB DIRECTIONS
Useful web addresses for electronics engineers.

BUDGET T&M ON A PC
Mention of audio cables elicits strong feelings in some quarters, huge yawns in others.
The HS801: the first 100 Mega samples per second measuring instrument that consists of a MOST (Multimeter, Oscilloscope, Spectrum analyzer and Transient recorder) and an AWG (Arbitrary Waveform Generator). This new MOST portable and compact measuring instrument can solve almost every measurement problem. With the integrated AWG you can generate every signal you want.

- The versatile software has a user-defined toolbar with which over 50 instrument settings quick and easy can be accessed. An intelligent auto setup allows the inexperienced user to perform measurements immediately. Through the use of a setting file, the user has the possibility to save an instrument setup and recall it at a later moment. The setup time of the instrument is hereby reduced to a minimum.

- When a quick indication of the input signal is required, a simple click on the auto setup button will immediately give a good overview of the signal. The auto setup function ensures a proper setup of the time base, the trigger levels and the input sensitivities.

- The sophisticated cursor read outs have 21 possible read outs. Besides the usual read outs, like voltage and time, also quantities like rise time and frequency are displayed.

- The (colour) print outs can be supplied with three common text lines (e.g. company info) and three lines with measurement specific information.

- The HS801 has an 8 bit resolution and a maximum sampling speed of 100 MHz. The input range is 0.1 volt full scale to 80 volt full scale. The record length is 32K/64K samples. The AWG has a 10 bit resolution and a sample speed of 25 MHz. The HS801 is connected to the parallel printer port of a computer.

- The minimum system requirement is a PC with a 486 processor and 8 Mbyte RAM available. The software runs in Windows 3.xx / 95 / 98 or Windows NT / 2000 / XP and DOS 3.3 or higher.

- TiePie engineering (UK), 28 Stephenson Road, Industrial Estate, St. Ives, Cambridgeshire, PE17 3WJ, UK Tel: 01480-460028; Fax: 01480-460340

- TiePie engineering (NL), Koperslagersstraat 37, 8601 WL SNEEK The Netherlands Tel: +31 515 415 416; Fax +31 515 418 819

- Web: http://www.tiepie.nl
More enthusiastic readers

I am glad to see that you readers know what you want. Yet again the mailbag was full of your comments — and I’ve printed a selection of them in the letters section. One reader has risen to the challenge of the Sciogie biography idea and if any reader has any information, recollections etc., I’ll be happy to pass them on and put you in contact with the collaborator and author — Chris Jones. His introductory letter is also in ‘letters’.

Certainly, the feedback I’m getting is much better than the recent reader survey, not that many of you replied. Apart from the eagle-eyed amongst you spotting various typos and my errors, there was a lot of positive feedback on what you want to see in the future. And just for the record — any mistakes in this magazine are down to me. It is my job to check everything — but sometimes deadlines and sheer blindness from reading something too many times creeps in. And quite why I found it so difficult to put the author’s name in the intro to an article (as opposed to just on the contents page) I cannot fathom.

Your letters certainly tell me what you don’t want. And it is interesting to know that you generally want more electronics and less computing — unless it relates directly to your interests. On that note, I’d be very interested in hearing what kind of design and emulation software you use — and also get some of you to review your favourite package.

I was quite surprised that only one reader had anything to say about the ‘Conspiracy theory’ (Letters, September). I know people in the medical profession that are convinced that excessive mobile phone use (when not used with a decent ‘hands free’ kit) can cause some nasty tumours around the head. Which is not surprising. Would you put your head into a microwave oven — of course not. So why expose your delicate parts to RF for quite long periods and expect to get away with it? It’s a shame that the mobile phone manufacturers did not do more work on the effects of their products.

I must apologise to the audio haters out there as I’ve inadvertently turned this issue into a bit of an audiofest. What with the continuing of Cyril Bateman’s ‘Capacitor Sounds’ series, Richard Black’s ‘Budget T&M’ which discusses the measurement of posh loudspeaker cables, the concluding part of Michael Kiwanuka’s VI protection in audio amps and Jeff Macaulay’s DIY MFB speaker, audio aficionados should be pleased.

The rest of you please accept my apologies and be assured that more non-audio features will be in next month’s issue.

Also for future issues, I’m currently in discussions with some contributors whose names you’ve not seen on these pages for a while. So, look forward to a bit of controversy from EW in the not too distant future.

I am also pleased to announce that the lucky winner of the ‘Worldspace’ radio competition is Kamal el Awad from Abu Dhabi. Kamal was the first winning entry pulled out of the hat by my assistant, Jackie. The radio will be winging its way to Dubai shortly.

I hope you enjoy this issue — and if you don’t — pick up your pen or keyboard and let me know.

Phil Reed, Editor.
Enhanced 'PICALL' ISP PIC Programmer

Kit will program virtually ALL 8 to 40 pin serial and parallel programmed PIC microcontrollers. Connects to PC parallel port. Supplied with fully functional pre-registered PICALL DOS and WINDOWS AVR Software packages, all components and high quality DSPTH board. Also programs certain ATXMEL AVR, SCENIX SX and EEPROM 24C devices. New devices can be added to the software as they are released. Blank chip auto detect feature for super-fast bulk programming. Hardware now supports ISP programming. 'A 40 pin wide ZIF socket is required to program 0.3" devices (Order Code AZF40 @ £15.00).

<table>
<thead>
<tr>
<th>Order Ref</th>
<th>Description</th>
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<tr>
<td>3144KT</td>
<td>Enhanced PICALL ISP PIC Programmer</td>
<td>£64.95</td>
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<tr>
<td>AS3144</td>
<td>Assembled Enhanced PICALL ISP PIC Programmer</td>
<td>£74.95</td>
</tr>
<tr>
<td>AS3144ZIF</td>
<td>Assembled Enhanced PICALL ISP PIC Programmer on ZIF socket</td>
<td>£89.95</td>
</tr>
</tbody>
</table>

ATMEL 89xxx Programmer

Powerful programmer for Atmel 8051 micro controller family. All fuse and lock bits are programmable. Connects to serial port. Can be used with ANY computer and operating system. 4 LEDs indicate programming status. Programs 89C1051, 89C2051, 89C4051, 89C51, 89LV51, 89C52, 89LV52, 89C55, 89LV55, 89S8252, 89LS8252, 89S53 & 89L533 devices. NO special software needed - use any terminal emulator program (built into Windows).

PC Data Acquisition & Control Unit

Use a PC parallel port as a real world interface. Unit can be connected to a mixture of analogue and digital inputs from pressure, temperature, movement, sound, light intensity, weight sensors, etc. (not supplied) to sensing switch and relay states. It can then process the input data and use the information to control up to 11 physical devices such as motors, solenoids, other relays, servo motors & two-stopper motors.

FEATURES:
- 8 digital Outputs: Open collector, 500mA, 33V max
- 6 Digital Inputs: 20V max Protection 1k in series, 5.1V Zener to ground
- 11 Analogue Inputs: 0-5V, 10 bits (5mV/step)
- 1 Analogue Outputs: 0.25V or 0.10V, 8 bit (20mV/step)

All components provided including a plastic case (140mm x 110mm x 25mm) with pre-punched and silk screened front/rear panels to give a professional and attractive finish (see photo). With screen printed front and rear panels supplied. Software utilities & programming examples supplied.

Serial Port Isolated I/O Controller

Kit provides eight relay outputs capable of switching 5 amps max and four optically isolated inputs. Can be used in a variety of control and sensing applications including load switching, external switch input sensing, contact closure and external voltage sensing. Programmed via a computer serial port, it is compatible with ANY computer & operating system. After programming, PC can be disconnected. Serial cable can be up to 35m long, allowing 'remote' control. Use easily write batch file programs to control the kit using simple text commands. NO special software required - use any terminal emulator program (built into Windows). Screw terminal block connections. All components provided including a plastic case with pre-punched and silk screened front/rear panels to give a professional and attractive finish (see photo).
Valve boosts PC sound

Aimed at audiophiles, Taiwanese PC maker component firm AOpen is making a motherboard with a thermionic valve sound port.

"It unquestionably is targeted to a very exclusive niche market - passionate audiophiles and extreme gamers who are interested in building their own ultimate entertaining PCs," said AOpen. "The motherboard is also certain to appeal to retailers that desire to cater to these two eccentric groups with custom-built PCs, delivered with matching speaker systems and the latest CD and DVD playback devices.

Satellite wakes from the dead

A US amateur satellite has burst into life after orbiting lifeless for 20 years.

"Oscar 7 seems to be running on power from its solar panels. The onboard batteries failed two decades ago. One likely scenario is that a short-circuit in the batteries opened, allowing enough power to operate the spacecraft while it is in sunlight," said AMSAT, an organisation which is still making and launching satellites.

The satellite, which was launched in 1974, was spotted by Pat Govan G3JOR who received CW telemetry and has since been found by many others. "Amateur operators have been monitoring the beacons at 29.502, 145.975 and 435.1MHz," said AMSAT.

Oscar 7 was the satellite that inspired the founders of now-successful Guildford-based Surrey Satellite Technology to first consider making their own spacecraft.

Cash for UK plastic solar cell effort

Cambridge Display Technology (CDT) is moving into plastic solar cell technology. CDT is already one of only two companies worldwide that have saleable plastic display technology - the other is Kodak - and now it has a DTI grant to use its expertise in semiconducting polymers to develop low-cost solar cells.

"Solar cells based on semiconductor materials such as silicon are expensive to manufacture and are limited to small area panels. The low manufacturing cost offered by polymer technology could make solar energy generated via polymer panels a viable commercial prospect," said CDT.

Belgian research organisation IMEC is already looking at organic (plastic) solar cells, as is the University of California, Berkley.

Although efficiencies so far seem to peak at around five per cent, compared with ten per cent for even the cheapest silicon solar cells, organic cells made in a continuous roll-to-roll process could be significantly less costly.

Efficiencies will also increase making plastic solar cells more desirable, but a significant problem could be ultraviolet stability as the sun's direct rays quickly alter the structure of most plastics.

CDT will be looking at indoor applications first, for instance in 'solar' calculators.
Pollution free in South Wales

South Wales students have developed some remarkable ideas for environmentally-friendly products on an industrial design course at the Swansea Institute.

Richard Clements has developed a three-wheeled scooter called PV1, his Public Vehicle for One, that could reduce traffic in city centres and is also pollution free.

"It's powered by a Stirling engine," said Clements. "I've got a powdered fuel made up from sodium, magnesium and iron."

Combining the dry powder with water results in an exothermic reaction, which provides heat for the Stirling engine.

Amazingly Clements said "there are no pollutants at all" from the reaction, in spite of the chemicals used. This fuel type is not new, but Clements said it is the first use in a Stirling engine.

PV1 has a claimed top speed of 50mph and runs for two to three hours at a time. Clements has applied for a number of patents covering the engine and tilt mechanism of PV1.

Meanwhile, John Briens designed a solar and wind-powered generator that offers a less polluting method of generating electricity.

"It's a portable, renewable energy source running off solar and wind power," he said.

Briens described the generator as looking like a golf bag. His design can deliver 12V at 1A continuously and "it can also run 240V stuff through an inverter", he added.

The unit weighs between 35 and 40kg, so would be suitable for transporting on vehicles, but can be moved to catch favourable winds or sunlight.

The environmentally friendly power source could be used in place of petrol and diesel generators on expeditions, Briens believes.

Matlab gets speed boost

The Mathwork, based in the UK in Cambridge, has updated its Matlab and Simulink tools, including the addition of just-in-time compilation to speed up Matlab's execution.

Matlab is perhaps the most widely used piece of signal analysis software, extensively used in universities and companies across the UK. The firm is aiming to bring it up to date with modern techniques.

Many users are being forced to hand code their algorithms in C in order to speed up execution during testing, according to Jim Tung, chief market development officer at The Mathwork.

"The problem with recoding is it's time consuming and it's prone to errors. People should not have to move to C just in order to get execution speed," he said.

Thus the firm decided to use a just-in-time (JIT) compiler. "We want to deliver the speed of a compiled language in an interpreted environment," Tung said.

JIT cannot speed algorithms that are already highly optimised, such as a fast Fourier transform, but general execution speed should rise by a factor of at least 50.

The Mathwork has also extended the tools, allowing them to model mechanical systems. This would be most useful when developing automotive, aerospace or industrial control applications.

And for the first time in five years the firm is supporting Macintosh users in the latest release of the tools.

These ant-weight fighting robots took a trip to Hursey EMC recently to deal with some EMC difficulties. Creator and engineer Peter Waller had been having a few problems with interference and receiver saturation - the latter from up to six competing transmitters clustered around the tiny fighting arena. Solutions were: more suppression on his wheel motors and shorter receiver aerials. The robots pictured are: ANTicyclone, CombatANT and MilitANT. Each weighs under 150g and fits in a 100mm cube. The next ant-weight championship will be in Aylesbury in October. www.robotwars101.com for ant-weight rules.
Nanotubes-to-go

Fujitsu Labs in Tokyo has developed technologies for vertical growth and diameter control of multi-wall carbon nanotubes.

Carbon nanotubes are touted as one way of connecting together future generations of on-chip components and in this development Fujitsu connected the tubes to the terminals of a mosfet.

Carbon nanotubes are usually produced using laser vaporisation and arc discharge, said the lab. However, these techniques do not offer good control over the location and orientation of the nanotubes, or the diameter of the nanotubes themselves.

Fujitsu used plasma-enhanced chemical vapour deposition using a methane-hydrogen composite gas at the same time as applying an electrical field perpendicular to the substrate.

The field induces the nanotubes to align with the field as they grow.

Of particular note, said Fujitsu, is the tubes grow directly on the mosfet electrodes on a contact material called a silicide.

Silicides are silicon-metal alloys - in this case with nickel or cobalt.

By varying the amount of Ni or Co, the diameter of the tubes can be set.

Surrey Satellite to use Russian rockets

Surrey Satellite Technology and Rosoboronexport of Russia have signed a contract to launch 8 microsatellites on 3 Cosmos rockets from the Plesetsk Cosmodrome during 2002-2004. "Cosmos and RBE were selected due to their capabilities to achieve the necessary orbital injection accuracy into a sun-synchronous orbit within the timescales needed by SSTL and at an affordable price," said SSTL.

Seven of the advanced Earth Observation microsatellites will be injected into the same orbit by the three Cosmos rockets in order to form the first international constellation dedicated to monitoring natural and man-made disasters.

The eighth microsatellite is a demonstration high resolution Earth Observation microsatellite for the UK British National Space Centre.

Seven of the microsatellites are being constructed by SSTL in the UK in collaboration with its international partners. Cosmos has an excellent record, said SSTL, and was previously used by SSTL to launch successfully its SNAP-1 nanosatellite and the Tsinghua-1 microsatellite for China in June 2000. The first launch for SSTL, carrying the first DMC microsatellite AISAT-1, is scheduled for autumn 2002.
Plastic chips get university backing

Polymer or carbon-based semiconductors are deemed so important that eleven UK universities have joined forces for research into the devices.

Moreover, the National Carbon-based Electronics Consortium goes further than pure research, and aims to improve the UK's record in transferring research into commercial products.

"The idea is to enable the UK to leapfrog ahead of international efforts in this area," said the group's leader, Professor Bill Eccleston from Liverpool University.

Devices using carbon or polymer circuits are increasingly finding applications, particularly in areas such as displays, solar cells and micromachines.

Sponsored by the Engineering and Physical Sciences Research Council (EPSRC), the consortium brings together the UK's leading players in carbon-based circuits.

The 11 universities involved are Bangor, Bristol, Cambridge, Heriot-Watt, Imperial College, Kings College London, Liverpool, Oxford, Surrey, Sussex and University College London.

It will hopefully improve the technology transfer of academic work to spin-off companies.

"As with liquid crystals, the UK is a leader worldwide, but unlike liquid crystals we do not intend to lose this position, and the EPSRC-funded managed programme will help to maintain it," said Eccleston.

Initial funding for the group from the EPSRC amounts to £2.7m, which should drive scientific and commercial work for three years.

Beside the universities there are around 15 companies involved in the consortium. Some of these were originally spun out of the universities themselves.

They include firms such as CRL and Epichem, which are developing products based on carbon technology, and notably CDT with its light emitting polymer displays.

Alongside the end products, the research efforts will look into growth and processing techniques and speculative research into combining carbon with other exotic materials.

The consortium also takes in 90 per cent of the academics working in the UK in the field, including Sir Harry Kroto, whose team discovered C60, or buckyballs.

Sewing with Windows - and GameBoy

Sewing machine company Bernina is making what it claims to be "the first authentic sewing computer," said Martin Favre, president of the company's US arm.

Called the Artista 200E, it has more than 850 stitch options and can sew in 16 different directions - and can also browse the internet using an optional PC Card modem.

Internet connection allows users to download additional features and embroidery patterns as they become available.

A USB port allows a CD-ROM drive to be connected.

The first sewing machine with a computer? - Try Nintendo.

Bernina is claiming "the first authentic computer", but Japanese company Jaguar got there first and has been making Nintendo GameBoy-based sewing machines for a while. Its range includes the Nuyell (which is sold by Singer as its 1eek), Nuotto and Nu-Yell.

GameBoys have quite a following as embedded computers - made popular by their reliability, input/output port, built-in display and rugged buttons.

There are several websites devoted to modifying GameBoys and companies produce custom interface cartridges that plug into its gameport.

There is an even a floating-point BASIC interpreter for GameBoy called GB Basic.

www.devs.com/gv is a comprehensive site and www.semis.demon.co.uk/Gameboy/Gbmain.htm includes a GameBoy digital oscilloscope.

Having Windows and a touch-screen on-board means the user-guide can be stored in the machine as well as video tutorials.

Sewers amongst Electronics World readers may be interested that the Artista 200E has a 14x25cm embroidery field, averages 600 stitches per minute and offers on-screen pattern editing.

Starter kit gets flash

Potential flash microcontroller users will benefit from Crossware's latest starter kit, which targets the Atmel range of devices.

The kit combines an evaluation board and development software. The board is fitted with an Atmel T89C51 controller, a 5V device containing 4kbyte of on-board flash memory. Other devices in the Atmel range include a 32kbyte chip.

Embedded code can be quickly developed, and the board is suitable for professional users, universities and hobbyists, the firm claimed.

The board can also be used as an in-circuit emulator. A header cable enables the board to be plugged into another system as the target device.

Larger prototype systems can be constructed via an IDC connector, linking the Atmel processor to other components. LEDs show activity on the various I/O lines.

Cambridge-based Crossware can be contacted at www.crossware.com
Low power radio firms under pressure

Companies whose short range devices (SRDs) operate within the unlicensed frequency bands are becoming increasingly concerned at Government plans to allow unlicensed spectrum to be used for commercial services.

The industry is worried that its SRDs - products such as car alarm fobs and garage door openers - will suffer from interference problems when commercial services start operating.

Current concerns are centred mainly around 2.4GHz. The Government has agreed to open up this licence-exempt band for public access wireless local area networks offering commercial services, which would allow the creation of internet access hot-spots.

Industry body the Low Power Radio Association (LPRA) sees the opening up of 2.4GHz as just one move which is fast eroding the spectrum allocated for its use.

"If you look at the spectrum... the amount that's actually allocated for SRDs is tiny," said Mike Brookes, chairman of the LPRA. "Yet everyone's saying 'this is the best bit of spectrum for our particular application'. The fact that it's free has nothing to do with it."

An 802.11b wireless LAN, which operates at 2.4GHz, is already being rolled out by Megabeam at a further 15 railway stations after a successful trial at London's Paddington station. Meanwhile BT started a public trial of an internet access hotspot service using 2.4GHz at the end of June and expects commercial roll-out to happen in August.

But the threat at 2.4GHz is far from the end of the story according to Brookes. Other concerns surround the introduction of HiperLAN and 802.11a, both of which operate at around 5GHz, another SRD band.

"These people have just said this is a wonderful bit of spectrum, it suits us down to the ground," said Brookes. "so we've got another hole being blasted right through the SRD allocation."

Brookes is particularly worried by the Government's spectrum review which is opening the way for this to happen. He believes the review basically boils down to 'let's open up everything to everybody' and is concerned it did not thoroughly investigate the needs of the low power radio industry.

Brookes said the amount of text in the report about SRDs amounted to "about a quarter of a paragraph", from which a lot of conclusions were drawn.

"I think it's dangerous the way it's going ahead. Everyone's jumping on the little bit of SRD spectrum to use it for commercial network services," says Brookes. "The danger is it will kill the SRD market which is largely comprised of small companies."

Smart whip saves horses?

In an attempt to quantify the amount of beating occurring during horse races, Dublin bookmaker Reg Cregan has invented The Register, a smart-whip.

Proprietary sensors in its tip measure each blow and inside its handle is an 8-bit Motorola microcontroller for data-logging.

Matlab from The MathWorks is used to process the data gathered by the whip either in real time or post-acquisition. This involves recording all waveforms, storing the time and amplitude of the waveform, then graphically displaying this data on-screen.

Bike firm CAN use the bus

The increasing use of CAN-bus in the automotive industry has spread to the motorcycle industry, with Ducati choosing CAN (controller area network) for its latest machine.

The Italian manufacturer is using the bus on the Ducati 999 in order to reduce weight. The two-wire digital bus links the dashboard to the Magneti-Marelli engine management unit. This simplifies the electrics and reduces weight, the firm said.

Various sensors and electronics on the bike connect to the processor in either the dash or EMU, whichever is closest.

CAN-bus is not the only first for the bike, as Ducati has also chosen to use samarium cobalt as the rare earth magnet in the generator's rotor. SmCo is more brittle compared to the widely used neodymium iron boron. However, SmCo will operate effectively at up to 350°C, while NdFeB falls over at 130°C.
Develop and test complete micro-controller designs without building a physical prototype. PROTEUS VSM simulates the CPU and any additional electronics used in your designs. And it does so in real time.

- CPU models for PIC and 8051 and series micro-controllers available now. 68HC11 coming soon. More CPU models under development. See website for latest info.
- Interactive device models include LCD displays, RS232 terminal, universal keypad plus a range of switches, buttons, pots, LEDs, 7 segment displays and much more.
- Extensive debugging facilities including register and memory contents, breakpoints and single step modes.
- Source level debugging supported for selected development tools.
- Integrated 'make' utility - compile and simulate with one keystroke.
- Over 4000 standard SPICE models included. Fully compatible with manufacturers’ SPICE models.
- DLL interfaces provided for application specific models.
- Based on SPICE3F5 mixed mode circuit simulator.
- CPU and interactive device models are sold separately - build up your VSM system in affordable stages.
- ARES Lite PCB Layout also available.

*E.g. PROTEUS VSM can simulate an 8051 clocked at 12MHz on a 300MHz Pentium II.
Readers of my recent articles have seen that many capacitors do introduce distortions onto a pure sine wave test signal. In some instances this distortion results from the unfavourable loading the capacitor imposes onto its driver circuit and frequently the distortion is generated in the capacitor.

When two or more signals are involved, a distorting capacitor produces a multiplicity of new frequencies. Used in an audio system, this can result in distorted sound. Fig. 1. Measurements are now made using a computer soundcard with FFT software, replacing the Pico ADC-100. The chosen software facilitates analysis, by calculating distortion relative to the voltage across the test capacitor. (see box Soundcard FFT Software.)

Many capacitors that distort little when sine wave tested without a DC bias voltage, exhibit much bigger distortions with increasing polarisation. With an 18 volt DC bias, the second harmonic of the capacitor in figure 1, increased by 23dB, but other harmonics hardly changed. Fig. 2.

Why should this be?
As a capacitor design engineer of many years, when I commenced these tests I believed that capacitor distortions would relate directly to the capacitor’s measured tanh. Dielectric absorption does not appear to significantly affect tanh measurements, so I reasoned it should not greatly affect a capacitor’s sound. I certainly was not alone in this belief.

More than 2000 distortion measurements have been made, using test signals from 0.1 volt to 6 volts AC and DC bias from 0 volt to 30 volt. Using a variety of capacitors, purchased for these tests and observing the effect of changing one measurement stimulus at a time, I was able to analyse the different distortions.

Starting in January 2002, these measurements together with their analysis, occupied many weeks. With a 30 minute warm up, my test equipment performed consistently throughout, producing exceptionally low distortion. I now realise dielectric absorption does influence measured distortions, even if the capacitor measures a low tanh on a bridge. (See box Tanh/ESR.)

As will be seen later in this series, when a capacitor is used with a significant DC bias, dielectric absorption becomes the dominant distortion producing mechanism. Whether these measurable capacitor distortions become audible or not, depends on the capacitor’s location in the circuit. The capacitor voltage levels, any subsequent circuit gain and whether the capacitor is located inside or outside of a negative feedback loop.

Repetition.
As a result, it became necessary to repeat most of my early single frequency tests, now using two frequencies. Distortion was measured both with and without DC bias voltage applied to the capacitor. To replicate many circuit voltage levels without over-stressing most capacitors, for this article I standardised on an 18 volt DC bias. Apart from Figure 1, the bias network was left in situ and switched to discharge for no bias measurements.

My 1kHz notch filter preamplifier was designed to attenuate 100Hz by some 55dB. A 100Hz test signal, similar in amplitude to the 1kHz signal, can be input without overloading the preamplifier or soundcard. 1

To apply a DC bias voltage across the test capacitor, a protective ‘DC Bias’ network must be used. I already had one, built using 100µF and 1µF metallised PET capacitors, used to measure capacitance change with applied DC bias, of capacitances up to 10µF. When tested with my near perfect 1µF KP test capacitor 2, this network introduced its own distortions. A new network was required. It was assembled using 11µF and 1µF MKP capacitors with a 100kΩ charge/discharge resistor. Another 100kΩ resistor to ground, protects the pre-amplifier input from charge/discharge transients, but restricts measurements to using 10kΩ and smaller sense resistors. Fig. 3.

This new DC Bias network permits accurate distortion measurements with dual 1kHz/100 Hz test signals up to six volts AC and with up to 50 volt DC bias. It is quickly attached to or removed from my existing test equipment. 3 It is designed to mount in place of the test capacitor, shown in the figure. (see DC Bias Network, Fig. 4)
Capacitor Myths.
Many articles have been written about capacitor behaviour, mostly by authors having little knowledge of capacitor design and construction. As a result, many false capacitor myths have emerged.

1. I will try to relate some of these myths to facts:
   a) All ceramic capacitors distort.
   b) Dielectric absorption causes smearing and compresses dynamic range.
   c) Polypropylene is an inefficient material.
   d) Capacitors are highly inductive at audio frequencies.
   e) ESR of a capacitor has a fixed value.

Capacitor production tests.
In manufacture every capacitor is measured for capacitance and tanδ, usually at 1kHz. Capacitance values of 100μF and smaller are measured at 1MHz. Capacitors larger than 1μF are usually measured at 100Hz. (See box Tanδ/ESR.) Each capacitor is “voltage proof” tested to ensure reliable operation at rated voltage. Leakage current or insulation resistance will be measured at the specified time interval or less. To expedite this time consuming measurement, leakage currents/insulation resistance are conservatively stated.

Many other tests will be performed on sample capacitors, to ensure compliance with National periodic ‘Type Tests’, but I know of no company that routinely tests for harmonic distortion, at realistic circuit voltages. Capacitors are not categorised for distortion, so a distorting capacitor would not be considered defective by its maker. It is the responsibility of the equipment designer to select the correct capacitor for each circuit requirement.

Tanδ measurement reflects both insulation resistance and series resistive losses. Invariably the LCR meters used include a “tuned” detector, designed to exclude extraneous frequencies. As will be seen, dielectric absorption affects the second harmonic, so is transparent when measuring tanδ. Fig. 2.

Dielectric characteristics.
In essence, two major dielectric characteristics exist, polar and non-polar. By polar, I am not referring to an electrolytic capacitor, but how the dielectric responds to voltage stress. This stress relates to the volts per micron gradient across the dielectric, not simply the applied voltage.

Vacuum and air are little affected by voltage stress and solid dielectrics which behave in a similar fashion are termed ‘non-polar’. Most solid dielectrics and insulators add or subtracting the appropriate dB levels to the vol file value, see Table. Spectra ‘Plus232’ can measure in real time, without first saving to disc. It can be used to cover the maximum frequency span of your soundcard, or as shown to measure over your selected frequency band.

Spectra ‘Plus232’ software was used for all capacitor distortion measurements, more than 2000 in all taken over several weeks, commencing with those for this article. Should you have only an older ISA soundcard, some software may not work. One that will, is FFT.EXE, a very simple, no-frills, DOS program by Henk Thomassen. This can be found on the internet and also on the Elektor 96-97 software CD-ROM.

Users having a modern PCI soundcard will find a very large variety of programs, often available as freeware, on the internet. One site that links to some of the better packages is www.pcauto.com/links/index.htm.

Figure 2: The figure 1 capacitor tested using 1kHz only with 18 volt DC bias. Compared to its 0 volt bias test, second harmonic has increased 23dB, a 14 times distortion increase.

Figure 3: A fly lead connected to the hot AOT resistor terminal, a duplicate set of source resistors and five 2.2μF-MKP blocking capacitors, couple the 1kHz test signal. The test capacitor output is fed to the pre-amplifier via a 1μF capacitor. A current limited 100Hz test signal may be input to the top left terminal, DC bias to bottom right.

Soundcard FFT Software
Measurements for my earlier articles used a Pico ADC-100. Many readers may wish to use a soundcard instead. A modern low cost PCI card with FFT software can provide increased dynamic range, measuring smaller distortions using my instruments, than is possible with the ADC-100. I now use the Spectra ‘Plus232’ software under Windows 98SE with a Soundblaster Live 1024 card, for all measurements.

With ‘CoolEdit’, the audio manipulation software already on my hard disc, I did try using it to measure capacitor distortions. Both ‘CoolEdit’ and the Pico ADC-100 software display distortion spectra but don’t calculate percentage distortion. Tired of making a great many repetitive calculations, I searched internet for a better solution.

I downloaded some twenty FFT packages for evaluation. On reading their help files, many were obviously of little use. A small number looked promising, because they provided a dB scaled display and calculated distortion percentages. However few packages promised any facility to calibrate and control the soundcard gain settings.

I decided the best choice was the Spectra ‘Plus232’ software. Ref. 6 I calibrated its input level using a known 1 volt signal. This calibration was accurately maintained from day to day. Having established a measurement set-up, it was saved as a ‘config’ file for reuse.

It also accepts a correction file, intended to compensate for microphone errors. Having carefully measured the output of my notch filter/pre-ampl by frequency using a 1 volt test signal, I wrote a correction file to restore the much attenuated test fundamental back to level and correct for pre-amplifier gain errors. The software then automatically displays percent harmonic distortion, on screen. Fig. 12

I quickly produced other files, from 0.1 volt test level to 6 volts, by simply adding or subtracting the appropriate dB levels to the 1 volt file values. See Table. Spectra ‘Plus232’ can measure in real time, without first saving to disc. It can be used to cover the maximum frequency span of your soundcard, or as shown to measure over your selected frequency band.
COMPONENTS

Figure 4: Low distortion test equipment measuring distortion of a capacitor with AC test signal, as described in my last two articles.
To measure capacitors with DC bias, the network of Figure 3 with test capacitor attached, replaces the test capacitor shown bottom right.

Figure 5: Distortion measurement of a Class 1 ceramic using 100Hz and 1kHz signals at 4 volts and 18 volt DC bias.
With no bias this tiny 10nF 50 volt C0G multilayer capacitor measured just 0.00006%. Second harmonic was -128.5dB, the other levels remained as shown.

Figure 6: A Class 2 X7R 10nF capacitor from the same maker as figure 5 and tested the same.
This test dramatically shows the impact an increase in both tanδ and dielectric absorption have on capacitor distortions.

DC Bias Network

Two DC blocking capacitors are needed, one to couple the signal to the test capacitor and the second to couple the test capacitor voltage into the pre-amplifier input. To minimise test signal loss, that capacitor should be ten times the value of the capacitor being tested.
To not introduce distortion it should be of much higher voltage rating than the DC bias and the same or better quality, as the best capacitor to be tested. I used five 2.2µF 250 volt MKP from BC Components (Philips), type 378 capacitors connected in parallel.
To couple the test capacitor voltage to the high impedance preamplifier input, a smaller value can be used. For this a 1µF 250 volt version of the MKP capacitor would be fine. I already had a distortion tested sample of the Epocs (Siemens) equivalent, so I used that instead. Source impedance resistors, as used in the buffer amplifier, are selected and connected to the AOT 'hot' pin using a short fly lead. Two 100kΩ charge/discharge resistors and a toggle switch, completed the bias network. Fig. 3.
All were mounted on a single sided PCB size 110 x 55 mm. For convenient interconnections, I mounted two lengths of the terminal strip, one on either side of the buffer. Fig. 13 To avoid overloading the soundcard input, the 100Hz/1kHz connections to the bias network should be completed before connecting the pre-amp output to the sound card.

are affected, increasing roughly in line with their 'k' value. This 'k' value is the increase in measured capacitance when the chosen dielectric is used to replace air.
Under voltage stress, electrons are attracted towards the positive electrode. The electron spin orbits become distorted, creating stress and a so-called ‘space charge’ within the dielectric. This produces heat in the dielectric with power loss, called dielectric loss, together with second harmonic distortion.
Non-polar dielectrics exhibit very small dielectric loss. Polar dielectrics are lossier and take longer for the dielectric to return from its original undisturbed state. Polar dielectrics produce easily measured 'dielectric absorption' effects, especially apparent in thin dielectrics.
Dielectric absorption is measured by fully charging the capacitor for several minutes then briefly discharging into a low value resistor. After a rest period, any 'recovered' voltage is measured. The ratio of recovered voltage to charge voltage is called dielectric absorption.

Ceramic capacitors.
'Ceramic' covers an extremely wide range of dielectrics, sub-divided as Class 1 (non-polar) or Class 2 (polar) according to the materials used to make up the ceramic. Class 1 ceramics do not use Barium Titanate and so have a low 'k' value. The best known is C0G. With its controlled temperature coefficient of zero ± 30 ppm, it was originally called NP0 by the Erie Corporation. It is non-polar and has a small dielectric absorption coefficient. From my tests, it has almost no measurable harmonic distortion. Fig. 5.
C0G ceramic provides the most stable capacitance value, over long time periods and temperature excursions, of all easily obtained capacitor dielectrics. It is frequently used as a capacitance transfer standard in calibration laboratories and yet as a small disc capacitor, it costs only pennies. Assembled as a multilayer, it can provide capacitances of 100nF and above, rated for 50 volts working, and can achieve higher working voltages for smaller capacitances.
Other Class 1 ceramics, sometimes called 'low k', provide increased capacitance within a controlled temperature coefficient, e.g. P100, N750 etc. in ppm. These also are non-polar and exhibit almost no measurable dielectric absorption. I have tested up to N750, sometimes called U21, and found very low distortion.
Class 2 ceramics do include Barium Titanate. It produces a very high dielectric constant, with 'k' values ranging from a few hundred to several thousands. Class 2 ceramic is strongly polar and its capacitance varies with applied voltage and temperature. It exhibits an easily measured
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Tanδ is used to describe capacitor quality. A textbook perfect capacitor has a phase angle of 90°, a phase angle deviation of 0°, a Tanδ of zero. Using a 6425 precision LCR meter, Tanδ of a most nearly perfect capacitor at 1kHz measured just 0.00005, a phase angle deviation less than 0.003°. These measurements were made on a Philips 10nF 1%, axial lead, extended foil and Polystyrene capacitor. Fig. 7
Some of the resistive losses which contribute to Tanδ are due to lead out wires and metal electrodes, so are relatively constant. Tanδ then increases with frequency. At 10kHz, Tanδ for this capacitor was measured at 0.00015 and just 0.0005 at 100kHz.
In past years capacitor quality was sometimes described as a ’Q’ value, the reciprocal of Tanδ. ’Q’ for the above capacitor was 20,000 at 1kHz, 6,666 at 10kHz and 2,000 at 100kHz.
Tanδ is measured using phase sensitive detectors, either by measuring the capacitor’s impedance and phase angle, or the capacitor’s resistive and reactive component vectors.

\[
\text{In which case,} \quad \tan_{\delta} = \frac{\text{resistive vector}}{\text{reactive vector}}.
\]

This resistive vector is called ESR.

\[
\text{ESR} = \frac{\tan_{\delta}}{\text{reactive vector}}.
\]

Obviously ESR must vary with frequency. At low frequencies, ESR reduces with frequency, up to the self-resonance of the capacitor. At self-resonance, the capacitive and inductive reactances have equal and opposite values, so cancel out. The capacitor’s ESR is then equal to its measured impedance. For that frequency only, it can be measured using a signal generator and voltmeter. At higher frequencies, ESR usually increases. The abbreviation TSR, for True Series Resistance, is often used by capacitor engineers to describe this minimal value of ESR.
The LCR meter readings for ESR of the above capacitor, recorded 0.8Ω for 1kHz, 0.26Ω for 10kHz and 0.08Ω for 100kHz.
Self-inductance reduces the capacitor’s measured reactance value. This means a capacitor’s self inductance actually increases its measured capacitance value.
A fuller description of Tanδ together with a proven measurement circuit was included in my articles describing the construction of an in-circuit meter.7 This meter was custom designed to identify good or bad PCB mounted electrolytic capacitors by measuring their Tanδ while in-circuit.

dielectric absorption, which increases with ’k’ value. Popular Class 2 ceramics include the X7R, W5R, BX capacitor grades and the exceptionally high ’k’ ZSU. These produce extremely large measured distortions. Fig. 6.

Film capacitors.
Film dielectrics have smaller ’k’ values, ranging from 2.2 for Polypropylene (PP) to 3.3 for Polycarbonate Terephthalate (PET).3 More significant than ’k’ value is just how thin the film can be produced and used to assemble capacitors.
Perhaps the best of the easily obtained plastic film dielectrics, Polystyrene is now becoming less popular. It has an N150 temperature coefficient, a very small tanδ and the smallest dielectric absorption coefficient of all film materials. It softens around 85°C and cannot be metallised or used thinner than 4 microns, to manufacture capacitors. Fig. 7.
For years it was wound with solderable soft metal electrodes, producing vast quantities of 1% tolerance, high quality capacitors, with values up to several µF.
All other popular film dielectrics can be metallised. They can be used to produce small, low cost, metallised film capacitors having a limited current handling ability. Alternately, using the superior foil and film assembly to produce larger and higher cost capacitors for the same value and voltage. Foil and film capacitors survive larger

Figure 7: This now discontinued Philips extended foil/Polystyrene 1% axial lead capacitor, with 4 volt signals and 18 volt DC bias, shows negligible distortion. With test signals increased to 6 volt and DC bias to 30 volt second harmonic increased less than 4dB and distortion to 0.00007%. There was no visible intermodulation.

Figure 8: The makers replacement extended foil/Polypropylene shows the same 0.00005% distortion but second harmonic is 1dB worse. With test signals increased to 6 volts and DC bias to 30 volts second harmonic increased just over 5dB, distortion to 0.00008%. Again, no visible intermodulation.

Figure 9: The small Wima FK2 foil/Polypropylene capacitor shows similar performance except for 2dB increased second harmonic. Distortion just 0.00008% with 6 volts stimulus and 30 volts DC bias.
Table 1

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AC currents, than metallised film types.
Metallised film capacitors rely on 'self-healing' to 'clear' minor insulation faults, so can be assembled using very thin films, their metallised electrodes adding almost no thickness. Capacitance is inversely proportional to dielectric thickness, so they provide a large capacitance in a small package. Conversely, foil and film capacitors cannot self-heal, so they must be made using film of sufficient thickness to withstand the required voltage without self-healing and being wound with metal foil electrodes.

PET has very high tensile and voltage strengths and is easily metallised. Film thinner than one micron can be used in 50 volt capacitors. It is polar with 0.5% dielectric absorption and a relatively high 0.5% tanh. Capacitance and tanh are strongly temperature and frequency dependant and with up to 3% capacitance change in two years, it has poor long term stability. A metallised PET capacitor rated for 100 volt may use film perhaps one micron thick. A foil and film PET capacitor might be made using five micron thick film. With five times the volts/micron stress, we measure more distortion with the metallised film type.

In contrast, non-polar PP, has a very small dielectric absorption of 0.01% and a low tanh of 0.03%. It has less tensile strength and is much more difficult to metallise. Assembling capacitors using PP film thinner than 4 micron is difficult, so PP is best suited to producing higher voltage capacitors. With dielectric losses only slightly higher than COG ceramic or Polystyrene and usable to 105°C, PP can provide large capacitance high voltage capacitors, suited for use on AC or DC. Since its introduction more than 30 years ago, it has produced the most reliable capacitors used in the high stress line-scan circuits of domestic TV receivers. PP is one of the most efficient, low loss dielectrics.

Capacitor connections.
For the best, undistorted sound, dielectric choice is obviously all-important. But using the best dielectric materials does not guarantee a non-distorting capacitor. A poor dielectric principally influences the levels of the second and even harmonics produced by the capacitor. An internal non-ohmic connection in the capacitor however, introduces significant levels of odd harmonics, the third having the biggest amplitude.

Disc ceramics use solder connections to a sintered, usually silver, electrode. Multilayer ceramics mostly use precious metal sintered end termination, with soldered wire leads. I have not found ceramic capacitors with non-ohmic end connections. All Class 1 ceramics I measured, have produced negligible and mostly second harmonic distortions.

From research carried out in Sweden by the Ericsson Company, a non-ohmic connection can exist in film capacitors. All metallised film and many foil and film capacitors use a 'Schoop' metal spray end connection to connect the capacitor electrodes to the lead-out wires.

I have measured many metallised film capacitors having very large third harmonic levels, frequently as much as +20dB higher than others in the same batch. I have not found this problem when foil electrodes are used with the same dielectric.

To avoid any possibility of a non-ohmic end connection we could use a solderable, soft metal foil electrode and solder it directly to the lead out wires. This is exactly the time proven assembly used by a large maker of extended foil/Polystyrene (PS) capacitors. It produces a near perfect, non-distorting, capacitor. Fig. 7.

Unfortunately, few manufacturers still make PS capacitors and many have changed their production over to extended foil/PP, retaining the soldered end connections.

Figure 10: Despite cleaning and re-tinning its oxidised lead out wires, this 1mF Mica capacitor, tested using 1kHz only at 4 volts and no bias, clearly has an internal non-ohmic connection problem.

Figure 11: Tested with no bias, this 0.1mF MKS2 metallised PET capacitor measured 0.00016% with clearly visible intermodulation products. With 18 volts DC bias, the second harmonic increased dramatically, from -119.0dB to -92.9dB and harmonic distortion to 0.00225%. 

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Polystyrene dielectric has almost unequalled electrical properties but softens at low temperatures, so cannot be flow soldered into a circuit board. It is also attacked by many solvents, so boards with unprotected capacitors are not easily cleaned.

**Self Inductance.**
Each electrode turn of an extended foil or metallised film capacitor is short circuited to every other turn, so contributes almost no self-inductance. Self-inductance of a capacitor body is then less than its equivalent length of lead wire. These capacitors have almost no self-inductance, apart from the 7nH per cm of the lead wires used to connect them into circuit.
By way of interest, I measured the resonant frequency of a 10nF 'Tombstone' capacitor. A vertical mounting, extended foil, axial wound capacitor. This construction has a small footprint but increased inductance due to its one extended lead out wire. The self-resonance frequency was above 10MHz. At audio frequencies, such small self-inductances are clearly unimportant.

**Low distortion choice.**
For the lowest distortion I still prefer PS, however from my measurements, it proved almost impossible to distinguish between an extended foil/PS and a similarly made foil/PP capacitor. Apart from small increases in second harmonic, measured for the PP versions. Both types are easily available from mainstream distributors in values up to 10nF. Fig. 7, Fig. 8.
For low distortion capacitors up to 10nF, my personal choices would be COG ceramic, perhaps also including discs up to N750, extended foil/PS or extended foil/PP, with the lead out wires soldered to the electrodes. Fig. 9.

**Alternative capacitors.**
Perhaps because of size, price, temperature range or voltage, the above small selection is not suitable. Stacked Mica is still available, but from my tests can be variable. I have some which are at least thirty years old with almost no measurable distortion. However, a small batch of 1nF, purchased specially for these measurements, distorted badly. One sample was even unstable, showing significant and variable third harmonic. Fig. 10.
I have measured very low distortions with Wima FKC2 foil and Polycarbonate capacitors. Bayer has discontinued production of Makrolon Polycarbonate film, so FKC2 capacitor production may cease. No doubt because of the thicker PET film used, I have measured surprisingly low distortion when testing Wima 10nF 100 volt FKS2 foil and PET capacitors. Results were almost as good as the FKP2 foil and PP of Figure 8. Tested with 30 volt DC bias, second harmonic distortion was only 2dB worse than for the PP capacitor. Unfortunately, this FKS2 style is not available in bigger values.
Having measured several hundred metallised PET capacitors, I have found many with extremely low distortions when measured without DC bias. I have also found far too many showing very bad distortions, with and without DC bias. Fig. 11.
For capacitances up to 10nF, low distortion, low cost capacitors are easily available. For example, using unmetallised PET capacitors, I have found one that is almost perfect with flat top and bottom frequency, measured for the PP versions. Both types are easily available from mainstream distributors in values up to 10nF, the near perfect COG, foil/PS and foil/PP types are not easily available. Our best options for capacitance values from 10nF to 1µF will form the subject of my next article.
Two further articles will then extend our distortion measurements to 100µF electrolytic, exploring our best options for these values.

**References.**
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2 BC Components 0.47±0.47µF 250 volt type 376 KP. Famnell part 577-881.
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Mention of audio cables elicits strong feelings in some quarters, huge yawns in others. Perhaps he needs to get out more, but Richard Black feels a strange fascination with the subject.

About 20 years ago a friend first demonstrated 'cable sound' to me, and ever since I have fondly believed I can hear differences between cables - both loudspeaker cables and small-signal interconnects. Millions of audiophiles across the world agree, and yet there has, to the best of my knowledge, been no convincing proof that the signal coming out of the end of Cable A is in any significant way different (within the audio band) from what comes out of Cable B given the same upstream equipment.

Several people have tried, notably Ben Duncan, whose measurements (published variously in Electronics World, Studio Sound and Stereophile) looked initially intriguing. What he claimed to have shown was variations in 'overhang' as a sinusoidal signal was gated off. Overlooking the fact that the gating, being of a transient nature, produces overtones into the stratosphere, what he actually measured was variations in the damping factor of the driving amplifier-plus-cable combination. On cutting off the signal, the loudspeaker continued to move mechanically, generating an EMF, which was damped by the low but finite impedance of the amplifier's output in series with the impedance of the cable. No surprise, then, that the higher resistance and inductance cables showed more 'overhang', and

Cable cobbler

Many manufacturers of audio cable have a serious foot-in-mouth problem. Sales literature and 'white papers' abound with some quite remarkable claims and assertions. Here are some particularly choice brief quotes, picked from relatively recent material from various sources, mostly sales material but in one case even a patent application. I make no comment!

1 Values of capacitance and inductance, clearly stated, which taken together must imply a speed of signal propagation in the cable greater than the speed of light.

2 The return, negative or cold conductor is greater in overall cross sectional area and mass than the signal, positive or hot conductor, based on a specific ratio that balances the flow of electrons, enhances electron movement and as a result improves signal transmission.'

3 'The self-inductive related rising impedance of the conductors, sometimes referred to as the 'skin-effect'...'

4 'Our cables .... are designed to have the lowest LCR specs and widest bandwidth on the market.'

5 'Second, the outer 'shield' is the most significant reason why the capacitance (C) and series inductance (Ls) of a 'coax' system is high and hard to reduce.'

6 'Without a proper inductive component, current cannot be stored....'
ultimately the tests did nothing but measure, by a roundabout route, the series impedance of the cable. Even earlier, Malcolm Hawksford produced several fascinating and rather daunting technical articles in Hi-Fi News which examined audio cables from a theoretical standpoint. Unfortunately, he didn’t produce much in the way of measured evidence and until recently there was proved nothing more than that signals travel through cables at a finite speed (typically 0.65c), which we all knew anyway – though it's surprising at first to discover how easy it is to prove that at only 20kHz.

In the circumstances it's been easy for those who wish to rubbish cable sound to do so in print, aided not least by some of the astonishing claims made by cable manufacturers (see box). But I've always had a desire to find some kind of mechanism that can plausibly explain audible differences between cables (or perhaps comprehensively to disprove it) and the test procedures outlined in the first and second articles in this series arose from my most recent attempt. Even if you are not the least interested in audio cables, the following example shows quite nicely how one can go rooting around in a test signal for clues, using a bit of audio-based software as the analysis and processing tool.

Differences between cables?
It's trivial to prove that different loudspeaker cables give slightly different frequency responses between a given amplifier and speaker and a small difference in overall level too. Typically one might be looking at differences in the order of 0.5dB overall, plus another 0.5dB at 20kHz of HF droop, between a low-resistance, low-inductance cable and some cheap generic figure-8 flex. Under ideal conditions those changes will probably prove just about audible. But not only are the alleged sonic differences between cables greater in extent (and different in kind, arguably) than 'mere' level and frequency response shifts, it is claimed that clearly audible differences exist between cables with much closer electrical parameters. If that's true, it surely makes sense to look for some kind of non-linear distortion mechanism, since our aural sensitivity to that is orders of magnitude greater than to level shifts, etc. Various people have proposed theoretical bases for such distortion in cables, ranging from rectification effects at crystal boundaries to the destabilising effect of the cable’s shunt capacitance on the feedback loop within the amplifier driving it. Again, none of these is proven (OK, the latter is obvious in extreme cases) but that's no reason not to try!

It is fairly simple to look for non-linear distortion, since it implies that the output of the distorting device will in general contain frequencies not present at the input. It was for this reason that I wished to develop quite sensitive, yet cheap and repeatable, tests for multitone intermodulation which would readily show up any non-linear distortion within the audio band caused by cables.

Since the amplifier used in the test was bound to have distortion of its own and its interaction with the cable is certainly of interest, it seemed most sensible to perform the tests so as to compare cables. Run the test with one cable, change to another, repeat the test and compare the results. Any change in distortion spectrum could indicate that the cable is indeed having an effect.

Basic test setup
The test set-up is very simple. I prepared a CD with four digitally generated (effectively distortion-free) sinusoids, not harmonically related, their frequencies were in fact 180Hz, 590Hz, 2500Hz and 13035Hz. This was played through a Rotel CD player and an EAR valve amplifier, driving an ATC SCM20 loudspeaker via the cable under test. A lead connected to the speaker terminals led to a Marantz professional CD recorder that logged the signal over several seconds.

In the hope of making things fairly obvious, I started with two very different speaker cables: Goulart M1 and Supra Ply 3.4. The Goulart has very high capacitance/low inductance, the Supra quite low capacitance/high inductance, and both have low series resistance. The spectrum of each is shown in Figs 1 and 2. Each is an average over 8 seconds, with an FFT length of 65536 samples. Each spectrum shows an array of distortion products, along with the stimulus frequencies, due to CD player and amplifier. But differences between the two? Next to nothing. Every distortion spike in one spectrum is there in the other, give or take at most a dB of level, and that's over a good 100dB of dynamic range.

Focusing
As discussed in my second article, it is possible to zoom in on a frequency range by means of filtering and modulation. Because it seems likely that any distortion effects due to cables should be more noticeable at high frequencies, let's examine the range around the top stimulus frequency. First, bandpass filter a narrow band, say 12.5kHz to 13.5kHz, using Cool Edit's FFT Filter with an FFT length of 24000 samples. It's a good idea to convert to 32-bit samples before doing this, so that at least the processing introduces no more noise. Then modulate by a 12.5kHz sinusoid using Cool Edit's 'Generate Tones' function. This produces a 1kHz-wide spectrum starting at 0Hz, with no increase in actual resolution but a big increase in viewable resolution using the log scaling in the frequency analysis window, Figs 3 and 4. The little
outcrop of frequencies around 19kHz is the other sideband produced by modulation, which one can easily filter off by using the FFT Filter again, as a lowpass.

As you'll notice, there's still no difference - though the very consistency of the spectra proves the power of this analysis technique, resolving details at least 120dB below the overall signal level. Repeating the bandpass filter/modulate process to narrow the band to 100Hz seems to get us no further. To increase the usable resolution still further, I compressed the waveforms to one-fifth their original length, raising all frequencies by a factor of 5. As Figs 5 and 6 show, there's still little to choose between them, a couple of dB or so between high-order intermodulation products offset a few Hz from the original stimulus. It's hard to believe that any of this constitutes an audible difference.

The next line of attack is to subtract one signal from another. In a slight variation of the test, I added a two-sample pulse to the 4 sinusoids every 10 seconds as a marker, so that they can be synchronised after the test. Unfortunately the recorder is not running in sample synch with the CD player, so the trick is to up-sample to the maximum Cool Edit will support (2MHz), synchronise to the nearest 250ns and subtract one from the other. Having located (by ear is easiest) the clicks, copy one second or so of the signal from one cable, starting a few samples before the click.

Create a new blank audio file of the appropriate sample rate (44.1kHz if you've recorded with a CD recorder) and 32-bit depth, and paste the section you've copied to the left-hand channel. Copy a similar second-long bit of the second cable's signal and paste it to the right-hand channel. From the 'Analyse' menu choose 'Statistics' to see how the levels compare, and equalise them as well as possible (Cool Edit allows level adjustment to 0.01dB). Now, using the 'convert sample type' option from the Edit menu, up-sample to 2MS/s, 32-bit. Set the 'quality' slider to 100 or so since there's little danger of aliasing.

Zooming in to high resolution, one can easily determine how much to delay which channel by so that they line up nicely. One neat way to do this is to set displayed time format to samples (right-click on the Cool Edit time axis bar) and select the audio between two supposedly synchronised points such as zero-crossings. You can then read out the exact delay required directly.

Measure a few points and average them to the nearest whole sample. After delaying, use the Channel Mixer to subtract one channel from the other. Resample to 44.1kHz since the higher sample rate is no longer any use, and look at the spectrum, Fig. 7. The stimulus frequencies are nulled by 30-50dB, which seems reasonable, but not all the distortion peaks are well nulled. A clue?

For a start, several of those peaks turn out to be mains harmonics which being in random phase relative to the stimulus will not null. But what of the patch around 1750Hz? Return to the original files, bandpass around 1750Hz, modulate by a nearby frequency: nearly identical spectra but presumably slightly shifted in phase, hence the failure to null. In other words, almost certainly not significant once again.

Tests with a couple of other cables produced similar results, as did high-resolution examination of other narrow portions of the spectrum.

Still no luck
This is quite a powerful test that should show up very small differences between cables, and all it has provided is evidence of level shifts, small frequency-response
shifts and phase shifts, none the least bit surprising based on the most rudimentary LCR analysis of the situation and none strong candidates for audible differences.

It is easy to advance hand-waving arguments about distortions that won’t show up on test with ‘steady-state’ signals, or that won’t show up as a voltage across the speaker terminals. None that I have seen will stand up to scrutiny, though. No, audio does not consist of pure sinusoids but given arbitrary constraints in time one can represent it to arbitrary accuracy by sinusoids and it’s a very well-proven system. As for signals not showing up, why shouldn’t they? Impedances are finite everywhere, so any current circulating will produce a voltage and vice versa. Even distortions due to noise pickup on the cables must eventually manifest as an AF voltage if they are to produce audible effects. I did actually try repeating the measurement with a microphone capturing the acoustical output of the speaker while it was driven through different cables, but as one would expect background noises were too high to allow really high resolution analysis.

It does start to look as if cable audibility comes down to a combination of level and frequency response changes and suggestibility (which is most certainly a strong factor in hi-fi comparisons). Lots of tests have been done on human sensitivity to those, and to phase shifts, which tend to suggest that cable changes should introduce only borderline-audible changes at most. However, the most sensitive tests I can think up so far show no evidence for any non-linear distortion.

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Figure 7: Spectrum of the difference between the signals via Goertz and via Supra, nulled within 250ns and 0.01dB overall level.
Letters to the editor

Letters to “Electronics World” Highbury Business Communications, Anne Boleyn House, 9-13 Ewell Road, Cheam Road, Surrey SM3 8BZ e-mail j.low@highburybiz.com using subject heading ‘Letters’.

Storm scope
I enjoyed reading Joe Carr’s article on lightning in the July 2002 issue of Electronics World. The “Storm Scope” described in the article looks like a very interesting device for monitoring lightning discharges at a distance. However, I wish to correct one statement in this article.
Mr. Carr seems to indicate that when Benjamin Franklin performed his kite experiment, a bolt of lightning struck the kite. This is a commonly held belief, which I have seen stated in several books. Franklin’s survival of this event is usually attributed to his use of a dry silk ribbon to insulate him from the lightning discharge.
However, historical accounts of the kite experiment do not describe an actual lightning strike. The best accounts are a general description of a kite experiment by Franklin himself, and a description of Franklin’s actual experiment, written by Joseph Priestly, read in manuscript by Franklin, and presumably verified by him. The kite had a “sharp pointed wire” attached, and the kite was to be flown “when a thunder-gust appears to be coming on.” The pointed wire collects the static charge of a thundercloud without actually being struck by lightning. The purpose of the dry silk ribbon is to insulate the kite string from the person holding the kite, so that the electric charge can accumulate on the kite and string, and not immediately discharge to ground.

I have been reading the piece on EMC (EW August.) What a muddle of ideas I read. I have worked in many areas of electronics, and have had to deal with EMC issues on several occasions. Star earthing is a vital tool in solving many situations. In audio amplifiers it gets round many earth loop problems. In RF it is a different story where ground planes are much used. In power engineering Star earthing can be a lifesaver. I know there are some occasions where it may cause problems, but these are very rare.

The basic idea, as most readers will know, is to limit separate earth currents from interacting, and causing noise to be spread around the circuit. The problem is that it is often misunderstood as to just how this really works. It can be explained in terms of a power amplifier where there are two parts the low power input, and the much higher power output stage. In order to prevent unwanted modulation of the low power input stage by the high power output stage. Separate supply lines should be used with a star earthing arrangement to prevent the re-circulation of ground currents. A ground plane here would be a good way to produce much hum.

Balanced plus/minus power rails also help to eliminate noise. Screening is also useful, if it is clearly understood just what is being screened out. Not all metals are of use in killing unwanted noise and several different means may be required to solve all the problems encountered in modern circuits. Stray circuit capacitance, or inductance can be a very difficult problem to cure.

Several years ago I was working for a then well known electronics test equipment manufacturer. They were part of what was then GEC. Because work was scarce they took on an order for traffic control systems including the Pelican system. These units were being assembled and wired when a young charge hand decided it would be quicker and look neater if the wiring was put into a nice loom rather than a point-to-point assembly. So several dozen of these were made up and fitted. The testers were surprised to find that the previously working units were now reporting strange errors. The upshot of this was that signals that had been posing without coupling now had plenty of way to do this. The units had to be completely rewired as before on a point-to-point basis. This shows that neat wiring does not always mean good wiring. It nearly superpered the whole order because of the extra time it took to change the wiring back to the correct layout. It can be that what looks wrong is in fact correct, I know from experience you can’t always improve on an idea. The wheel still works rather well for me.

Ian Johnson
By email

EMC
I have been reading the piece on EMC (EW August.) What a muddle of ideas I read. I have worked in many areas of electronics, and have had to deal with EMC issues on several occasions. Star earthing is a vital tool in solving many situations. In audio amplifiers it gets round many earth loop problems. In RF it is a different story where ground planes are much used. In power engineering Star earthing can be a lifesaver. I know there are some occasions where it may cause problems, but these are very rare.

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Ian Johnson
By email

the loose filaments of the kite string sticking out as they became charged and repelled one another. Franklin then produced an electric spark by bringing his knuckle near the metal key attached to the string. Clearly this is a case of a static charge building up on the kite and string, rather than a terawatt of power flowing through the apparatus.
The distinction between a build-up of static charge on the kite and an actual lightning strike is important, and not just for historical accuracy. One must realise that the reason Benjamin Franklin was not harmed in the kite experiment was not because of the electrical insulation of the silk ribbon. It is doubtful that the ribbon would have provided any significant protection if the kite had been struck. He survived because he was fortunate that the kite was never struck by lightning. He avoided a strike by flying the kite before there were actual lightning strikes in the vicinity. However, lightning is unpredictable, and he could easily have been killed, like others who attempted this experiment.

Although Mr. Carr’s article clearly emphasises the danger, I fear that many of the other accounts of this famous experiment inadvertently downplay the danger by misrepresenting the role of the silk ribbon. And by claiming that the kite was actually struck by lightning. The kite experiment was pioneering, and important in the development of modern electrical theory, but there is no need to repeat it in the twenty-first century. And, as Mr. Carr points out, there is certainly no justification for the risk involved.

Joe Borrello
Portage, Michigan, U.S.A.


Here’s a recollection to add to the July 2002 article by Joe Carr on “Observing Lightning”. I grew up in Drumheller, Alberta, Canada in the
1950s and the closest AM radio station was in Calgary about 100 miles away. Drumheller is in a deep valley and to get better reception on my poor performing cat whisker crystal set I decided to build a bigger antenna. I had over a 1000 feet of No. 20 shot wire left by an oil seismic exploration crew and decided to use it to form an antenna going up the side of a hill. I used a post-hole auger to drill about 7 holes and installed some 10-foot poles using the finger hole of inverted glass wine jugs for insulators. My hobby space shared the basement with the coal furnace. I installed the antenna leading along a floor joist and brought a ground wire in along an adjacent floor joist that were on 16-inch centres. The crystal set worked much better on the long antenna and my attempts to improve it included making a bigger coil that took me below the BC band. I started listening to modulated CW aircraft beacons. As summer storms approached I could hear weird, strange whistling sounds and assumed that these sounds had something to do with the storm. Many times the noises were so loud that they and the static crashes were hard on the ears so I'd leave the basement. One afternoon my mother went into the dark basement and immediately came running out yelling that my apparatus was going to start the house on fire. I went to investigate and saw sparks jumping between the feed and ground wires. The parallel wires 16 inches apart were insulated but the charge was strong enough to break through and make a colourful display in the dark basement for the entire length of about 20 feet. My mother insisted that I stop the sparking before the house caught on fire. I grounded the antenna lead and my mother was satisfied but a few days later when my dad saw the sparks I had to take the antenna down. That led me to make a regenerative receiver that worked well with my 25 foot stub antenna. The article has rekindled my interest and I think I'll build some VLF equipment and listen but with a shorter antenna unless I can find a nice hill and a dark basement.

73

Henry Kolesnik
WDSJR Tulsa, Okahoma, USA.

Your thoughts

I thought I would e-mail you after reading your comment on "reader enthusiasm" in the September 2002 edition of EW.

I would like to see more circuits and articles in the area of microprocessing, and micro controllers, this seems to be the current area of electronics and one that personally interests me. I've started to program PIC Micro controllers and am fascinated by their capabilities.

You may be interested to know that I am only 15 years old, and have been reading EW for a bit over a year now. Although it has progressed over time with a few more micro controller circuits, but they are not very frequently occurring.

Danny Schofield
By email

I am quite anxious about the future of EW as it is the only remaining Electronics magazine worth reading: full of original articles and ideas and innovative projects (I'm mainly interested in audio and analogue circuits).

Considering the August issue, I was disappointed that the name of some authors was omitted, that the second part of C. Bateman's distortion meter was not present and the Tony Meacock's circuit idea was already published in the previous issue. I also have a request more than twenty years ago, P.J. Baxandall started a series on the design of power amplifiers in the then called EWWW.

Six parts were published but the series was never finished. I would love to read the remaining parts if they were written.

Sébastien Veyrin-Forrer
France

Do any readers know the answer? - Ed

I've noticed in the last couple of months that something like 50% of authors' names have disappeared from their Electronics World articles - it's necessary to refer back to the index page to get this information. Is this intentional? If so, it's not helpful, particularly when it comes to 'selective archiving' of past articles of special interest.

Otherwise, keep up the good work.

Joe Graham.

By email.

My fault entirely - Ed

Just read your editorial for September issue. Am now worried as to where the mag may be going. Been reading the thing for 33 years now and have watched on as it has changed form, content (and spine thickness), during this time. From what you are suggesting as a potential new direction, I can see the mag resetting itself to a situation about 6-7 years ago when I stopped buying it.

I'm a freelance electronics design engineer who lives and breathes the subject. In 33 years, I've never met another reader of the mag, yet I'd be willing bet money that most of your readers (who pay cash for it), are of similar motivation.

What I want to see in it, is electronics, electronics and yet more electronics.

-Computer articles, small networks, software reviews, enabling technologies, digital imaging, video and audio compression, Bluetooth, LANS etc, are not 'electronics'. They are purely the guff of marketing departments and programming companies. I'd also include WAP, mobile phones, the internet, connectivity, multi-media, broadband, switching power supplies, digital busses, ASICs, PLAs, Digital and terrestrial TV, 'personality' interviews, any marketing department press releases and unfortunately, "Tackling interference problems on 433-92MHz" and "Spectrum pricing's uncertain future".

I want to see stuff from the likes of Ian Hickman, Cyril Bateman Doug Self etc. I want to be amazed as to what Kamil Kraus can do with a single op-amp a C and an R. I want to see lots and lots of circuit ideas and readers letters. I'd like to see some general technical comment from masters of the art. I'd like to read discussion of the technical fine details of classic test and instrumentation kit. Articles on oddball aspects of some unusual circuit arrangements. Some of the interesting historical aspects of our industry. More of the weird science stuff and a lot on product design philosophy. Some items on 'neat' methods of getting a particular

Spring conundrum

Can you help me - I keep having a nightmare where I am bouncing on a spring mattress and my thoughts are rather over the top for a man of 77 years who has read Wireless/Electronics World for around 60 of them. The mattress has sets of two springs connected by string with the separate springs slackly restrained with further strings.

I am worried that if I bounce up and down too much and the connection string breaks, will I shoot through the ceiling or be smothered in a collapsed mattress and I hate to think what would happen if the restraining strings also break.

Or alternatively would Hot Electron tell me the answer to his spring conundrum (July White Noise). I calculate that the springs P & Q are originally in series but if the string X is cut they would be in parallel and the weight would go up - No! Too easy. Well, it seems to depend on several variables so back to the mattress.

N.L. Smith
Stoke-on-Trent, UK.
result and some case studies of equipment design.

I want to be educated and informed in all things electronic and not feel I’m being patronised by some moronic marketing gobshite.

If you move in the direction you have indicated then yes! the advertisement revenue will return. yes! the magazine’s financial future will be more secure. It will never ever gain the respect of Wireless World as was. It will never be mentioned as a point of reference. It will never reside in the pocket of bright-eyed young engineers as they make their way in the world. It will be just yet another glossy, trade, advertising mag. An accountant’s revenue stream or business resource? Electronics people like me will not be paying cash for it, nor will any electronics authors be writing material for it.

The reason the electronics publishing world is falling apart in the U.K and has been for many years now, is that no one (especially young ‘uns) is any longer interested in making the effort to acquire the considerable body of knowledge and skills needed to earn a decent living in this particular industry. Why bother when the trivial effort involved in web site design, or the media or money markets etc, brings vastly greater reward? It’s a cultural problem with no particular end in sight. Just look at the endless queues of wannabees for the ‘pop idol’ series. From Electronics World’s POV and in line with no doubt, its accountant’s driving for financial return. I reckon it should be aiming itself precisely at those readers who have stuck with it for god knows however many years.

Ask ‘em how long they’ve been reading it and why. You’ll find most of ‘em are born engineers who are compelled to read it just like smokers are addicted to the weed. Remove the cigarette and you will not be selling the product.

The captive market of existing and incoming electronics enthusiasts will still be reading something of general value. Let it be EW.

To hell with the accountants! Take the risk! Aim for a reverence and respect within the real electronics industry. God knows we need something to point to. (Not the transient flim flam of the marketing world). Grab the real engineering people and hold them. They’ll see you through thick and thin year in and year out. The book world has “The art of electronics” the mag world has zilch. Wireless World lost it when it started to take the trade shilling. Don’t send EW further down that same path.

Personally the only mags that have ever really caught my attention have been the first few issues of ‘ETI’. Most of the ‘Electronic Engineerings’ and WW’s from the sixties and every single priceless issue of the ‘Ambit International’ house magazine by Bill Poel.

The biggest most significant and improving change that can be quickly made to the present mag is to get all those shine, amateurish, author? supplied circuit diagrams, redrawn into a pleasing, uniquely styled, EW standard format. (Costs £ though!).

John Jardine.
By email

It certainly does cost - but I’ll see what I can do. - Ed

It’s good to know from your Electronics World editorial that you’re employed in the electronics industry!

Just a little feedback: the readership of Wireless/Electronics World has dropped from 50,000 copies per month twenty years ago to something like 15,20,000 now. The editorial department twenty years ago was a half-dozen strong, including technical editorial assistants and layout designers.

Electronics applications have blossomed during the last twenty years, so why the factor of 3 or 4 decrease in readership?

Competition has not increased, since the number of electronics titles then was just as plentiful as today. It seems that successive publishers have sought to tailor the magazine to a core readership, progressively losing news-stand sales. If you ask subscribers, they will tell you that they want electronic design features. But if you ask the casual buyer in the newsagent, they will tell you that something in particular caught their attention while browsing.

What happens is that catering for a common core of readers trims off the casual browsers, and loses 40,000+ readership.

If you look back in the archives to the heyday, you will see that the magazine has become progressively more focussed on technical and theoretical topics, and has lost the wider focus.

I hope that you will try to broaden the sales pitch - if your publisher allows you - to include a special territory of Electronics World to include computer developments, wireless networking, and that old favourite - the ‘building your own’ series. Circuit ideas and design hints are fine fodder for the expert, but to draw in new readers and student engineers you should be publishing instalment articles on how readers can cheaply build their own modern electronics gear from components.

I reckon that ‘build your own top-spec laptop with instant boot up every time’ (by having the operating system in flash memory, instead of on the hard disc) would be worth a try.

Nigel Cook
By email

I would most strongly advise against going down the path of all things computer orientated. This would lead to the loss of at least one reader, myself being that one. There are plenty of other publications dealing with all things computer, whether hardware or software. Elector and EPE, to name but two. Electronics Today International failed for this very reason.

Your readership requires a good mix of electronics articles, covering everything from simple audio circuits, up to more complex RF circuits. OK, if there is a special territory of computer related circuits should be included put it to the readership. They will vote with their wallets won’t they?

At one time far too many audio related circuits of doubtful value were published and I for one gave up buying Electronics World for about a year until it went back to a better mix of subjects.

I would like to see more on unusual electronics, or the out of the ordinary type of things, something to exercise my brain. Why follow in others

Circuit idea re-visited

Fernando García’s article in the December 2001 issue on hysteretic regulators reminded me of the May 1976 issue of Wireless World in which a circuit idea from V. R. Krause appeared. It contained a non-conventional use of a 7805 to realise a ripple regulator. I think that it would be worthwhile to repeat it.

Jean-Marc Brassart
Saint-Laurent-du-Var, France
footsteps when you can lead the field?
Try to keep the unnecessary pages of maths to a minimum, it fools nobody when an article is simply several pages of theoretical equations. I was never much good at this highbrow stuff.
I have always been a very practical person, developing my own circuits, and in thirty years I have never built any magazine based designs. The thing is they never cover my requirements. I repair electronic equipment for a living. I have most test equipment and many thousands of components. The one thing I would like is a simple design for a good RF spectrum analyser. There have been one or two but they were far too expensive, using so special semiconductors that were very soon obsolete.
That is the crux of the matter - finding parts that will be around for more that a few months and that don't cost the earth. Well some food for thought.
As I write this a big thunder storm is nearly over head so I will have to terminate my writing here before that fateful stroke of lightening crashes over and kills this machine and me with it. Bye for now.
Ian Johnson
By email

I am very pleased with the latest editions of EW. Recently, I was talking to the owner of an electronics shop, one of very few left here in Denmark. He was complaining that so few were interested in real construction activities nowadays, so his main source of income was PC odds and ends, batteries and lamps. I found a wealth of inspiration reading WW and its successors, and competitors like ETI and Elektor. My first issue of WW is from 1971, and I still keep it. This interest later became my livelihood, working for the audio recording industry for many years, and these days I'm designing 'High End' audio equipment for OEM manufacturers in several countries. Although I do have a very respectable set of measuring equipment, the wonders of Audio Precision set-up is still out of my reach.

In a correspondence I asked for more constructional articles and practical articles about the new inexpensive measurement and simulation techniques, within reach of so many readers with access to PC hardware.
I find that the subjects are now being treated in the present and future issues, especially delightful is the

article on capacitor sound, that may well put in a sense of reality among the subjectivists - and Mr. Bateman both demonstrates the constructional ingenuity of a modern day Lindsey-Hood using PC measurement and simulation, and builds a low cost high class measurement system to prove his points. I for one will be duplicating his designs as soon as possible. Please forward my respect and praise to Mr. Bateman, for writing a great many useful and entertaining articles over the later years.
And since the June 02 issue, Mr. Richard Black is taking us the budget route to advanced electronics analysis, again with inexpensive PC soft- and hardware.
A suggestion: I would very much like to see a practical article about low cost intermodulation distortion measurement using PC hardware for analysis of audio equipment. So much has been written on THD measurement, but so little about IMD, TIM etc. Could you ask Mr. Black, please?
And Mr. Black and Mr. Bateman could perhaps work together, making a synergy of their work, if possible and a broader, more practical approach for Mr. Black? He is going through a very interesting field much too fast, surely a more in-depth approach is due?
In the past, some of your contributors have seen fit to present simulation results as the infallible gospel, along with some hand waving.
In the future, please ask them to present the simulation net lists, conditions and models on an internet site, so we all may look over their shoulder. Learn from their wisdom and duplicate the result.
So now I only miss a good series of educational articles on the ins and outs of PC simulation, by someone who will cover the subject thoroughly. In the past, there have been several articles on the subject but mainly for a specific purpose. What I (and maybe others) do need is a roadmap and a progression of simulations using real world designs as the object, and demonstrating the tricks, pitfalls and advantages of such programmes.
I am aware that a great number of simulation packages at widely varying prices exist, so for the proposed series, a shareware or freeware package with schematic entry should be used as the demonstration software to allow as many readers as possible to participate.
I am certain that a commercial

software vendor will jump at the chance of this kind of exposure.
While I understand that a source of income for your writers may be found in selling readymade printed circuit boards, I would very much like to see a way of downloading these layouts, for example in the form of a 300dpi windows bitmap file, or other generic graphic format that will allow the necessary detail to be printed out. Maybe a modest fee per download could be set as a compensation for the authors that will also serve as a popularity indicator for the magazine?
For a quick prototype, following the DIY methods of Mr. Bateman and others is not too difficult.

Michael Edinger,
Denmark

A warm welcome to the "Electronics World" editorial position! Your name is familiar to me from the IBE magazine. (I too have been in the broadcast industry for many years) and I look forward to reading your "worldly wise and cutting" comments in the future in EW.

I have been regularly reading Wireless/Electronics World for several years - more then I would like to mention..!, and by chance I recently stumbled on my copy of Wireless World from the Queen's Jubilee year (June 1977). The first thing that was obvious was that the occasion was marked by a special front cover for the 25th Jubilee together with a short column looking back to the state of affairs then 25 years ago in 1952. Very fascinating stuff!...
A photo of a WW from June 1952 was shown on the Jubilee front cover, at the time costing 2 shillings (10p)! In 1977 the price is 40p and today £2.95.

On looking through the copy from 1977, I think you might agree that the change in the electronics industry is much less marked in the last 25 years leading up to the Queen's Golden Jubilee than the previous quarter century. In 1952, semiconductor devices and microprocessors were still yet to come and the valve reigned king. By 1977 the situation was reversed and already firm/software based electronic devices were becoming common. Silicon integrated into digital and analogue "chips" were and still are fundamental building blocks for the industry. Looking back from 2002 however, some of the most significant changes in recent years include information and data transfer via internet, the use of a PC for design, simulation and testing electronic systems, and gradual loss of the ability to repair modern circuitry down to a component level. (It's just getting too small to see!!) I wonder what the next 25 years will bring?

Sorry, I forgot to mention that the editorial article in the June 1977 WW was about "Radio and Air Safety". That is something which is still very much in the public focus in 2002 - some things just don't change do they!!

Peter Sullivan

By email

Good luck with the new job from a WW/EW subscriber of very many years, although with a break some years ago when the magazine seemed to have lost its way.

An issue on which it might be worth commissioning an authoritative article is the controversy now being aired in RSGB's RadCom (May 2002 p28 and subsequent issues) about whether the Crossed-Field Antenna does anything more than any other bit of metal put up in the sky.

Authoritative but also comprehensible to self-taught amateurs like me, please. The late, great Scroggie could have done it. Hickman, perhaps, or Bateman?

Can I suggest a little more care with final proofing? (I expect someone has mentioned already the desirability of not publishing the same item in consecutive issues, so I shall not labour that point.) For example, the article on p46 of the September issue seems to start at the second paragraph. The letter "Exposure" on p57 refers to "brackets on which a polycarbonate carrier simply rests on." Perhaps this error was in the original email, but it should not have been published. And your editorial: whose, not who's.

I wonder if there should be either more careful scrutiny of Circuit Ideas or a disclaimer of the "Untested - you're on your own" variety on the page. I think more may be needed than the disclaimer on the editorial page. For example, R1 in the first item on p30 is at best a bit under-specified, if that is the term, and possibly a source of fire risk, especially if replaced as suggested in the text with a 47K resistor. And what purpose does C1 serve?

Should it be necessary to go to the 'Contents' page to identify the authors of articles?

Some of these points are rather trivial; but easily avoidable mistakes create an impression of scrubfiness and more importantly may engender thoughts in the reader along the lines that "if they can't get simple things like that right, can I rely on them in more complicated matters?"

Pleased to see that there will be no more long software listings. Please do not let EW become yet another computer magazine.

John Compton
Southampton

Double sided PCBs

When making printed circuit boards I went through most of the stages described by Cyril Bateman in the May and June issues of Electronics World. But I have a few points that may still be of interest.

1) Transparencies. As Mike Harrison, I use tracing paper in A4 pads. With REI on 'dark' the Density on '5' and the paper routing through the back, my Laserjet 4L printer gives good results with 65 GSM paper.

2) Registration. My PCBs are limited to 160 x 100 mm. If more is needed I use more boards. The printed transparencies are cut to 120 mm width. The sheets have more then 60mm free on each end. The top and bottom sheets are put together and exactly aligned. Light through small 0.6 mm holes in the isles shows whether alignment has been reached. If so, the transparencies are glued together at the 120mm outer rims. The registration can be checked and corrected if needed. The sheets are now placed between two plates of 6mm Perspex, each 210 x 145 mm, see sketch. They can be screwed together with six M4 bolts and have two alignment pins along the outer rim, glued in the hole of one plate. The 145 mm ends of the Perspex plates get a bit of water-soluble glue on the inside before the sheets are clamped between the plates. The sheets stick out of the Perspex plates, whose ends are cut off. If you take the plates apart each transparency sticks to its plate. You now may put the photosensitive material in place and screw the second plate on top. The alignment pins make sure the registration stays correct. Making double sided ICBM, single or multiple, is no problem any more.

3) Etching. I changed from ferrichloride to ammonium- or sodiumpersulfate to avoid yellow stains. I do not premix the etching chemical but use about 20 grams of persulfate per 100 square centimetre of copper (35mμ) to be removed. A digital kitchen scale with a 1 gram resolution was bought for this purpose. The chemical is diluted with 5ml water per gram. The water used is initially at 55 degrees Centigrade and is kept above 45 degrees by rocking the plastic etching container in a hot water bath. After 5 minutes the first copper is off and another three minutes are needed to remove all of it. The amount of liquid is rather small, however complete coverage of the PCB surface has not been a problem. The etching container should be some 200 x 110 x 60 mm and be slightly deeper in the middle, to avoid scratches. This method gives the same results each time and avoids crystallisation of partly used chemical solution. The spent etching chemical is retained and accepted by our local chemical removal service. This liquid may create a bit of oxygen gas, so do not completely close the storage container until after some time.

4) PCB design. Until recently I removed all copper from a PCB that was not needed for its electronic function. This is environmentally unfriendly. The present aim is to leave all copper on the PCB that does not interfere with its function. Connecting tracks are isolated from each other by 0.5 to 1 mm wide openings in the copper. The amount of chemical used is a lot less than what was needed the old way! Maybe I have to return to premixing and reusing chemical solution in order to wet all copper surfaces.

T. R. Mortimer

Spellng or Grammar?

You really ought to fire the staff-member who let out your editorial with "who's" instead of "whose" in it. If he or she does it again we'll see "it's" for "its" in your learned journal. It's bad enough re-naming it "Electronics World", but now there's electronic spellng chequers, and grammar chequers even, there ain't no excuse for it, know wo' I mean?

T. R. Mortimer

Vlssingen, the Netherlands
MOSFET compensation

In his letter in the April 2002 issue, Mr. Kessler brought up, quite rightly, the way the Miller compensation was applied to the original Hitachi MOSFET amplifiers. Regarding the first design, one of the capacitors must have been unintentionally omitted from the diagram because otherwise this amplifier is definitely unstable.

Regarding the second design, he wonders why the compensation capacitors on both halves of the second long-tailed pair are rated at different values, in fact 36pF and 10pF. Presumably, it’s an attempt to equalise the currents trough both capacitors. As pointed out by D. Self, this matters, as the two signal paths from input stage to the next stage must have the same bandwidth. However, I’m afraid this cannot be achieved at all, since the voltages across these capacitors are completely different.

There is a way around this problem by omitting both capacitors and compensating by means of a single capacitor that also includes the input stage, (see figure). This scheme is based on a design by Linsley Hood (who’s name is strikingly absent from the list of references, why?) The advantage is that most of the current from the first stage is available as input for the next stage, rather than being consumed by the compensating capacitors, hence a higher slew rate and lower transient intermodulation distortion. Furthermore, the unity-gain frequency of the global feedback loop is almost exclusively determined by R7 and C20. The internal loop (via C20) is stable due to the loading by the MOSFET output stage (for a 1RF240/8RF240 pair, typically 280pF) and gate series resistors (typically 100Ω). So inserting drivers between second stage and output stage or using MOSFTs with a much lower input capacitance may impair the stability. To improve the phase margins, C21 and R20 are added. Note that R20 x C20 roughly equals the time-constant of the gate series resistors and effective input capacitance of the output stage (50x x 280pF). According to my simulations, the internal loop has an unity-gain frequency of 16MHz and a phase margin of 83°, while the global feedback loop has an unity-gain frequency of 2MHz and a phase margin of 85°. The slew rate has improved to 100V/s. Apart from this, I added Schottky diode D2 to make the quiescent current of Tr3 and Tr4 less temperature dependant.

With regard to the two-terminal current source, I have no reason to doubt it has excellent characteristics. However, Mr. Kessler did not explain how to apply this circuit to the amplifier, although the article he referred to, is concerned with current sources in the second stage. Therefore I assume he suggests applying the circuit the same way as Dr. White did: as a replacement of R9 and C4. In my letter of January 2002, I disapproved of this kind of practice. Dr. White replied, but missed my point* and also apparently Mr. Kessler, as he proposed an even better current source, where essentially a short ought to be. So I take the opportunity here to clarify my objections. My concern was not how the current source was implemented, but why it was put there anyway and so robbing the second stage from its ability to sink and source quite large amounts of current (>30mA). In principle, one can tie the collector of Tr3 directly to Tr5/D1 (see also ref.2, fig 9). As stated in my previous letter, the only reason why R9 is present is to reduce the power dissipation of Tr3 and to provide protection in case of overloading. C4 is added to avoid loss of AC-gain. Replacing RWC4 by a current source not only cripples the second stage, but creates instabilities as the output of Tr3 shows such a high impedance, that it can be considered as a current source too. I’ll repeat, connecting two current sources in series is not done. Moreover, it could be dangerous. Suppose the current source is rated slightly higher than the current Tr3 can sink, then the current source becomes saturated and Tr3 is exposed to almost the full supply voltage, thereby (possibly) exceeding the maximum power dissipation. If the current source is rated slightly lower, then Tr3 collapses. This kind of instability has already been described (and cured) by Linsley Hood (ref.2, fig.12).

Dr. White replied that neither Tr3 nor the current source was saturated. With careful adjustments not impossible, at least under quiescent conditions, but certainly not when the second stage is spurred to action. He claims a distortion of 0.005% at 1kHz and 1W. Again, not impossible, as my Spice simulation, that shows a tendency to flatter results, indicates 0.002%. However, at 20kHz and 1dB below full power, simulated distortion rises to 0.16%, sixteen times more than he claims. Slew-rate was claimed at 35V/s, while simulation reveals a meagre 12V/s. It is not my intention to criticise Dr. White and Mr. Kessler, because they are seeking methods to improve performance. Instead, I strongly recommend using a simulator, as this is the easiest way to explore new ideas and to reveal potential shortcomings that are otherwise hard to detect. As a starting point, the demo version of Micro-Cap4 suits this application well, because it has sufficient numerical precision for thd analysis, and it is free. Appropriate Spice models must be obtained from other sources.

Edmond Stuart
Amsterdam, The Netherlands.

References
4. www.spectrum-soft.com
**Experimenter’s pendulum timer**

We needed an experimental set-up to check the acceleration of a pendulum due to gravity. The circuit we devised starts with a 555 configured as a monostable, Fig. 1. Its trigger input is fed by a light-dependent resistor. A pulse caused by the pendulum bob briefly interrupting the light impinging on the LDR triggers the monostable.

Output from the monostable forms a clock to two bistable devices. Output Q1 of the first JK bistable device clocks the second.

Output Q3 from the second bistable device feeds a 555 timer configured as an astable multivibrator with a period of 0.01s. While Q3 is high, pulses from the astable multivibrator pass through to the decade counters. These counters are followed by decoder/drivers and displays for indicating units, tens and hundreds.

Fig. 2

To take readings, the pendulum the bob is taken to extreme right, i.e. point N on Fig. 3, and then released. Figure 4 shows the pendulum and sensor set-up. The pendulum passes the LDR three times each period, Fig. 5.

Heights of the LDR and

---

**Fig. 1. First section of the pendulum timer circuit comprising the gating pulse monostable, top left, gating bistable devices, top right, astable clocking timer, bottom left, and the units counter/display, bottom right.**
CIRCUIT IDEAS

lamp relative to the bob can be made adjustable using pillars.

Figure 5 shows the pendulum pulses from monostable relative to output from the two bistable devices.

Knowing the period \( t \), the velocity of pendulum swing, \( g \), can be evaluated.

The relationship of the pendulum is given by:

\[
\frac{1}{2} \pi^2 \frac{1}{g} \frac{1}{t^2}
\]

Therefore,

\[
g = 4 \pi^2 \frac{1}{t^2}
\]

To illustrate, \( l = 40 \text{cm} = 0.4 \text{m} \) and the time period of the astable device is 0.01 s. The display count is 127 so \( t_p \) is the period of the pendulum, which is 127 x 0.01 s, i.e. 1.27 s.

On substitution in the above relationship for \( g \):

\[
g = \frac{4 \pi^2 \times 0.4}{(1.27)^2} = 9.791 \text{ m/s}^2
\]

Switches X, Y and Z are

initialisation resets. Normally, the astable is in its reset condition. By momentarily pressing Y and Z several times after the pendulum passes point N in Fig. 3, fresh counter readings can be obtained. Several readings can be obtained for different lengths of pendulum and an average taken.

V. Gopalakrishnan
Bangalore
India

V. Gopalakrishnan
Bangalore
India

Fig. 3. Illustration showing the positions of pendulum points M and N.

Fig. 4. Outline of the set-up showing how the pendulum interrupts the light source.

Fig. 5. Key waveforms. Top is output from the first monostable, while bottom is the final gating pulse for the astable-configured 555.
Speaking clock with an educational display

This clock is unusual. Seconds are displayed in binary, minutes with decimal numbers and hours via an LED "analogue" pointer. Last but not least – the clock can speak.

To make sure this design was accessible to those involved in education, the circuit was put together using traditional components. The design’s purpose is to demonstrate binary digits, gates, counters, display units, decoders, etc. Seconds are displayed in binary-coded decimal format and minutes using seven-segment LEDs. Hours are shown with a 'pseudo-analogue' LED-pointer.

Voice output is implemented using an ISD memory chip, which can store one minute of voice recorded via the microphone. The chip is binary addressable. When triggered, it outputs the recording starting from the active memory address.

In this design, I have recorded declarations of full and half hours to various addresses so that as time proceeds, the active address contains the message related to that time. Voice output is triggered by the minute counter when reaching value ‘00’ or ‘30’.

How it works

Timing reference IC1 contains frequency dividers so that exact 1Hz signal are available from pin 14. Higher frequencies can be taken from other pins. One second cycles are taken to a decade counter, IC2, the status of which is displayed in binary using LEDs. Counter overflow triggers count to six counter, IC3, whose count is displayed in binary as well. Thus the seconds are indicated in BCD with two rows of LEDs. Minutes, handled by IC4, and tens of minutes, IC5, are counted in the same way, but their statuses are taken via decoders IC7 and IC6, to seven-segment displays.

Hours are counted with a count-to-twelve counter, which comprises four-bit binary counter IC6. This chip is reset back to zero with a positive pulse to pins MR1 and MR2 when the counter reaches its maximum. Thus the clock face has normal 12 hour increments, without day and night separation.

The hour counter output causes one of the BCD-to-decimal decoder, IC9, outputs to fall to zero, activating the hour-pointer LED. These LEDs are spread around a circle, as on a clock face.

As the decimal-decoder only has ten outputs, extra decoding via IC11 is needed to display hours from 10 and 11.

The binary value feeding hour counter IC9 is also taken to address lines A4-A9 of the voice chip, IC8. Address line A9 is fed with a signal indicating full hour (0) or half hour (1). The lowest address lines, A0-A3, are grounded, so the storage is divided into 32 slots of 5 bits. Of these, the first 24 are used.

Speech triggering requires a negative going pulse to pin 23 (CE), which is generated when output from IC2 (pin 8) goes to ground. This happens when the output of the tens of minutes decoder, IC9, achieves the value "0" or "3". When that happens, loudspeaker L outputs the message from the memory slot pointed to by address bits A4-A8.

Message recording

Using five address bits, the memory is divided into 32 parts, the length of each of which is about 2 seconds (60/32). In this design, only the first 24 are needed. Other memory slots thus have 2 seconds of time, but the last one can use up to (32-24)×60/32 = 15 seconds.

Declarations of time, e.g. "it is half past five" or "it is ten o’clock" must thus fit into 2 seconds, but at 11.30 there is lots of time to explain that "it is half past eleven now."

Recording is performed by speeding up the clock using S3 (IC4, pin 10) to the desired time, 6.30 for example, and stopping there by taking S3 to its neutral position. Note that all values between 6.30...6.39 will do, because single minutes are not included in the chip address formation.

Push button S1 and speak the desired message, e.g. "it is half past six." After recording S1 is immediately released and thus the end-mark is generated. You can

![Image](image-url)
immediately verify that the recording was successful. Briefly push \$2 and the speaker should output the stored message. If also now other messages are heard, you have exceeded the two-second limit before releasing \$1. No problem. Simply repeat the operation.

Note that recordings and their contents can be changed at any time, if the old ones start to sound boring. When all time slots are recorded, drive the clock to right time and switch \$3 to normal position.

Power supply
Provided that there are no power failures, the clock keeps time accurately. Normally, power is supplied from a small adapter via regulator IC1, but it is supported by a battery to overcome possible mains failures.

As battery voltage does not exceed 5V, \$3 keeps it disconnected under normal operation.

Putting it together
I assembled my prototype on two PCBs. Display components were soldered to a vertical board (clock face) and others to a horizontal board joined to the other.

Switches are in the back panel. The front panel of the box is darkened Plexiglass, through which only the active LEDs are visible. To make the clock face visible, hours are marked with small green LEDs that are permanently turned on. These are not shown in the circuit diagram. Red LEDs indicate the latest full hour. Minutes and seconds are indicated in the middle of the display.

The whole device, including speaker and microphone, is built into a wooden box measuring 10cm by 10cm by 15cm.

Heikki Kalliola
Helsinki
Finland

Telephone in use indicator
I designed the circuit described here to provide an indication of a busy telephone line when another family member is on the phone.

A ringing indicator is also provided that lights a second LED when AC ringing voltage is present. The circuit is simple, draws less than 150μA from the line and around 10μA from the battery in its idle state. About 4mA is drawn from the battery when the line is busy. The circuit is also isolated from the mains supply and input overload protection is provided.

In the idle state, line voltage is around 50V, dropping to around 20V in the busy condition. Zener 2D1 acts as a simple comparator switching \$T1 off when the line is busy, allowing \$T2 to conduct through the high value resistor \$R3 and lighting LED2.

A high-gain transistor – one with a gain of more than 250 – should be used for \$T1. In addition, a low current LED should be used to preserve battery life.

Ringing current passes through \$C1 and the negative half cycles are removed by \$2D2. The resulting signal causes \$T1 to conduct, lighting LED1. Diode \$2D3 also provides protection for \$T2 and \$R1, and allows the gate/source capacitance of \$T3 to be discharged after ringing pulses.

Resistors \$R2 and the neon lamp provide input overload protection of up to 350 volts, AC or DC. The neon lamp can be replaced with two 68V 1.3W zener diodes connected back to back. Capacitor \$C1 should be rated at 250V DC minimum.

I have had the circuit running for over a year on the same set of AA alkaline batteries. A Darlington opto-isolator or a low-current Reed relay can be used in place of the LED if you need to drive external devices with the circuit.

Alistair Borthwick
Edinburgh

Mobile phone triggered combination lock
This electronic combination lock is unlocked when the circuit recognises a unique valid sequence of four tones from a mobile phone. This unique code is easily changed if need be. Note that the phone is used "off-line" so no phone expenses are involved.

One great benefit compared to a traditional code lock is that no door keypad is required. Installing is thus cheaper and simpler and there are no visible targets for vandalism.

The door to be locked needs only a small hole for a microphone, which can be very small. It is not essential to locate the microphone near to the lock.

In addition to forming the basis of a combination lock, this circuit can be used to operate anything that runs off electricity.

How it works...
Pressing a mobile phone button generates a so-called dual-tone multiple-frequency, or DTMF, code whose frequencies depend on which key is pressed.

The circuit receives DTMF tones via its microphone and is set by the user to respond to a unique four-digit code using switches. After amplification, the DTMF signal received at the microphone is directed to a DTMF receiver. IC2, which converts it to a 4-bit binary format.

Received digits are stored as four, 4-bit words in the 16-bit register formed by IC3. The digits are converted to decimal using BCD-to-decimal decoders IC4. When a new digit is keyed, the previous ones are shifted forward.

The diagram, in the last entered digit is in the left.
This combination lock is triggered by a unique set of four DTMF tones produced by pressing the keys on a mobile phone. The combination code is set using four 9-way DIL switches.

### Parts list

**Resistors (0.25W)**
- R1.2: 47k
- R3: 1.5k
- R4: 330
- R5: 1k
- R6: 33k
- R7: 5M trimmer
- R8: 100k
- R9: 380k
- R10: 200k trimmer
- R11: 10k

**Capacitors (16V)**
- C1: 0.47µ
- C2: 47µ
- C3: 1µ
- C4.5: 100nF
- C6: 6.8µ

**Semiconductors**
- LF357: IC1
- 4015: IC2
- 4028: IC3
- 4047: IC4
- 4081: IC5
- 2N2222: Tri
- 1N4001: Di

**Miscellaneous**
- Electret microphone: M
- 5V Relay: RL1
- 9-way DIL-switch: S1-4
- 3.579545MHz crystal: X
0-5mV to 4-20mA converter based on chopper stabilisation

Here is a circuit that has industrial uses. I built it to amplify a 0-5mV input signal - in my case from a transducer in a Wheatstone bridge - and convert it as accurately as possible to 4-20mA form.

I developed the circuit to help me carry out some research into thermal conductivity, but it has many other potential uses. The equation of this converter is simply:

\[ \text{Output (mA)} = 4 \text{mA} + 3.2 V_{\text{in}} \]

Here, \( V_{\text{in}} \) is expressed in millivolts (0-5). To make this equation work, you need a stable voltage gain of 8000, or 58.1dB.

My converter owes its accuracy and 140dB open-loop gain to the classical chopper amplifier. This amplifier comprises two stages: an integrator making about 60dB of gain and an integrator making about 80dB of gain.

Total open-loop gain amounts to 140dB. This is controlled globally by a 1+R12/R16. The total gain available is the product of that produced by IC1b and IC1c.

Since the open loop is so high, it is possible to obtain 60dB amplification while still leaving 80dB spare for the closed loop. This results in incredible amplification accuracy. As shown, the circuit is set to 60dB which equates to a voltage gain of 1000.

Both zero and span are accommodated, allowing for a two-point calibration. Calibrating the converter to the above linear equation is relatively simple. Once it is corrected calibrated, a quick linearity test can be carried out: adjust the input voltage test source to 2.5mV and the circuit should yield exactly 12mA output.

Oscillator IC2a operates at around 500Hz. It drives the two FET switches, \( T_1 \) and \( T_2 \), which commutate synchronously. Since IC1a's signal path is isolated by way of C1, C2, and C3, ambient temperature drifts have negligible effect.

Next, IC3a converts the signal from voltage to current. This allows level shifting to take place. The signal then
appears across $R_{31}$ and equally across $R_{32}$ and $R_{34}$.

In conjunction with $T_{4}$ and $T_{5}$, $IC_{3}$ forms a variable 4-20mA current source. The range of the output termination resistance of the 4-20mA signal spreads from zero to in excess of 1000Ω.

If you prefer a voltage output then simply terminate the 4-20mA signal with a 250Ω, 0.1% resistor for 1 to 5V output.

Normally, the input signal will be from the output of a wheatstone bridge with one of the arms being the transducer. In order to maximise CMRR from the bridge, the bridge should have an isolated supply. This not only knocks up the CMRR to around 150dB, but also accommodates the classical chopper's single-ended input (reference ground 0V) very nicely.

While most transducers are very slow — they can take minutes to respond — the converter has an adequate bandwidth of about 20Hz. This can be altered by changing RC time of $R_{17}C_{6}$.

Since the converter is mains powered, there is a small residual 100Hz signal riding on the final output. Obviously, increasing the speed of the integrator will increase this residual. This unwanted signal comes about because the bridge rectifier acts as a mixer, generating many low frequency components in the supply.

After building this design, I tested the ICL7650S. This is a complete chopper on a chip, but it has a drastically different architecture from that of the classical chopper shown here. I found that the 7650S works extremely well. At a guess, I would say both schemes work equally well. However, my converter is extremely low cost and has supply and low output impedance (wide swing) advantages over the ICL7650S. Most importantly, it is nice to know that there are alternatives to using the 7650S.

Darren Heywood
Buckley
Flintshire

Since finalising this design, Darren has found that reducing the oscillator frequency to 60Hz gives a significant increase in performance.

Circuit CAD on a shoestring

Needing a means of drawing circuits in a presentable fashion and in such a way as they could be easily modified using existing software, I decided to have a look at PC Paint. A few hours of practice mixed with some frustration resulted in my building a small component library that makes the job of drawing circuit diagrams much easier and provides quite acceptable results — importantly, at no extra cost.

First, open the symbol library in one PC Paint window and then start the circuit drawing in another. It is a simple matter to 'copy' from the symbols window and 'paste' to the drawing. Once a symbol is used in the drawing, it may be copied and pasted from within that window.

I've found that most drawing operations are fairly easy to perform with a 200% magnification. PC Paint gives three levels of 'undo' in case you make a mistake. You can select between the circuit and symbols windows by clicking the appropriate icon on the task bar at the bottom of the screen.

The library contains all the components I have used to date, but there is room for plenty more to be added. I suggest creating them at 400% magnification so that fine details can be drawn. This magnification is the highest that PC Paint will allow.

With practice comes proficiency. For me, this method has turned PC Paint from being an unfriendly monster into a useful tool. 'Flips' and 'Rotates', available by selecting the symbol and right-clicking on it, allow components to be orientated as required.

Minimum file space for saving drawings is attained by reducing page size to just fit the drawing (Image. Attributes menu) and saving the work as a monochrome bitmap. Remember to save the work frequently, just in case your computer crashes or there's a power cut.

Malcolm Watts
Wellington
New Zealand

Section of the author's bitmap file. For a copy of the file, e-mail John Lowe ehighburybiz.com using the subject heading CAD file.
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**Wire harness saves 45% PCB space**

The 1.25mm (0.049in.) pitch Mini Mill wire harnessing connector system from Molex is designed to save about 45% of PCB area compared to similar 2.00mm (0.079in.) pitch versions for applications such as printers, home appliances and automotive telematics. The system can carry 1.5A and is available in wire-to-board and wire-to-wire configurations in 2 to 20 circuits for single row and 10 to 40 circuits for dual row. It features a common singletowire IDT receptacle that provides mass termination of discrete wires. The receptacle has guide slots to facilitate wire placement. Side ribs provide polarisation and lock into a clip for dual-row configurations. Header options include single or dual row, SMT or through-hole, and vertical or right-angle.

Molex
Tel: +44 (0)1252 720720
www.molex.com

**36 Mbit quad data rate SRAM**

Samsung Electronics has announced its first 36Mbit Quad Data Rate II (QDRII) SRAM memory device designed for high-performance telecoms applications. The device is compliant with the recently approved JEDEC specification for QDRII SRAM architectures. It has a 250MHz bandwidth and 1.8V operating voltage. Unlike the conventional synchronous SRAM, QDRII memory device has two data ports that run independently at Double Data Rate (DDR), resulting in the transmission of four data words per clock cycle, allowing it to process four times as much data as conventional networking SRAM. In addition, it offers a wide data-valid window of 65% of the clock cycle, facilitating ease of system design. The device is available in a 15 x 17mm 165-pin FBGA package, recently standardized by JEDEC.

Samsung
Tel: +44 (0)49 6196 683514
www.samsungsemi.co.uk

**DSL modems get low voltage switch ICs**

A family of low-voltage analogue switches and multiplexers introduced by Siliconix Vishay are pin and function compatible companions to higher voltage CMOS devices. The family includes five monolithic quad SPST analogue switches (DG411L, DG412L, DG441L and DG442L), two single SPST analogue switches (DG417L and DG418L), a single SPDT analogue switch (DG419L) and two precision analogue multiplexers: the 8-channel DG408L and the dual 4-channel DG409L. Typical turn-on time for the switches is 20ns and insertion loss is 3dB at 280MHz. All devices are specified for 2.7V to 12V single supplies or ±3V or ±6V dual-supply operation. The devices provide a logic interface, breakbefore-make switching action, ESD protection to 2000V, and are available in SOIC-16 or TSSOP-16 packaging.

Vishay
Tel: +44 (0)191 5144155
www.vishay.com

**Quarter brick with dual voltages**

SynQor is offering a dual output voltage quarter-brick sized isolated DC-DC converter. The DualQor series is capable of delivering up to 60W of total output power at ±12V and -12V, without the need for an attached heatsink. The converter module employs synchronous rectification and a patented topology to achieve efficiencies up to 92%. The converter has a 48V nominal input (35 to 75V range) and meets input voltage transient requirements up to 100V for 100ms.

SynQor
Tel: +44 (0)49 621 784322

**Power resistor rated to 1500W**

Designed for applications where traditional heatsinking is not practical, the BPR series high power resistors from Tyco

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**Mobile processor with camera**

Hitachi's second version SH-Mobile application processor, the SH7294 incorporates a SH3-DSP CPU core with an operating frequency of 120MHz, and features enhanced camera support and display functions. The device is intended to support the development of next-generation mobile phone systems with built-in cameras. Working alongside the baseband chip of the mobile phone, the device performs dedicated processing of multimedia applications such as audio and moving pictures. It has its own development platform and middleware, including face-authentication and fingerprint-authentication software, as well as more typical applications such as MPEG-4, JPEG, and MP3.

Camera support functions enable direct connection of a VGA-size (640 x 480 pixels) camera. According to the supplier, this is expected to be the standard camera for next-generation mobile phones as it enables capture of high-definition images and electronic zoom display. The SH7294 is available on its own and as part of the HJ93D1705BP Multi Chip Module (MCM), which incorporates 1Mbyte SRAM, stack-mounted. The package used for the SH7294 and the MCM is a 10 mm x 10 mm x 1.4 mm, 0.5 mmpin pitch, CSP-225 package.

Hitachi
Tel: +44 (0)1628 585163
www.hitachi-eu.com
Wireless LAN chipset for 54Mbit/s

Intersil has introduced a dual-band 802.11a and 802.11g wireless LAN chipset capable of transmitting high-speed video, voice and data at speeds of up to 54Mbit/s while remaining backward compatible to the 802.11b WLAN standard. The chipset features baseband processor and medium access controller based on direct down conversion (ZIF) architecture. Its dual-band OFDM-based (Orthogonal Frequency Division Multiplexing) technology communicates with both 2.4GHz and 5GHz WLAN devices.

Intersil
Tel: +44 (0)1276 686886
www.intersil.com

16-bit flash micro has boosted program speed

Hitachi has introduced its first microcontroller to incorporate its fourth generation flash technology. The H8/3069F is a 512kbyte flash microcontroller supporting faster programming, on-chip firmware for simplified handling and a user boot program area. It is aimed at industrial and consumer applications. The H8/3069F combines 512kbyte flash with 16kbyte SRAM on-chip. At 2.5s for 128kbytes, the flash write speed is approximately three times faster than current Hitachi products. The on-chip firmware is designed to shorten development time by eliminating the need for a user-written control program and making software more reliable and future-proof, said the supplier.

Hitachi
www.hitachi-eu.com

C++ compilers for PowerPC, Xscale and MIPS

Wind River has released version 5.0 of its Diab C/C++ compiler suite which includes optimisations for specific microprocessor architectures including PowerPC, Intel Xscale and MIPS. It allows software developers to create an executable program by taking application code written in a high-level language such as C or C++ and converting it into machine language that runs on the target application. It supports PowerPC, MIPS, Motorola 68K and ColdFire, ARM, Intel xscale/StrongARM. M CORE. Hitachi SH, Mitsubishi M32R, SPARC. SPARClite processor families. Host support includes Windows 95/98/NT/Win2000, Solaris, HP-UX and Linux host machines. The next release of Tornado II/VxWorks platform for which Diab 5.0 has been integrated will be available later this summer.

Wind River
Tel: +44 (0)121 6281888
www.windriver.com

72Mbit SRAM has no bus latency

Ramtron is sampling its 72Mbit no bus latency burst enhanced SRAM (ESRAM), which uses a...
BGA/flip-chips get reworkable underfill material

Loctite is supplying reworkable underfills for flip-chip, BGA (ball grid array) and CSP (chip scale package). Although designed for use without underfill, CSPs and BGAs can experience mechanical and thermal shock and the use of an underfill material can provide a stable interface between the package and the PCB. The Loctite underfills can be rigid or flexible at operating temperatures and heating the material will allow it to be reworked. 

Loctite
Tel: +44 (0)1442 233233
www.loctite.com

Auto microcontrollers get a roadmap

Infineon Technologies has announced a roadmap for its next generation of microcontroller chips for engine and transmission control systems.

The AUDIO-NG family of 32-bit microcontrollers is based on the firm's TriCore unified processor architecture, which incorporates a digital signal processor in the core.

The family will initially comprise three 32-bit microcontrollers; The TC1766 and the TC1796, both of which are based on the TriCore 1.3 architecture, and the TC2700, which uses the TriCore 2 architecture and will be capable of clock speeds up to 400MHz.

An extended peripheral set includes a MultiCAN module with up to four CAN (controller area network) nodes and Time Triggered CAN (TT-CAN) functionality, a fast analogue-to-digital converter module operating at ten times the conversion speed of previous models. A multiprocessor interface is geared to the requirements of power train applications. This interface enables a number of AUDIO-NG microcontrollers to exchange data streams and is an essential prerequisite for the development of future drive systems with intelligence distributed over multiple processors.

The TC1766 offers clock speeds in the 80MHz range. The TC1796 operates at clock speeds up to 150MHz.

Infineon Technologies
Tel: +44 (0)49 89234 22767
www.infineon.com

Low gate voltage Mosfets have low RDS(on)

Fairchild Semiconductor has introduced low RDS(on), N-channel, 20V Mosfets which are designed for DC-DC converter applications, with low gate voltages down to 1.5V. The FDS6572A and FDS6574A N-channel devices are designed to replace 30V parts in point-of-load power supplies and other low voltage power management applications, especially where low gate drive voltage is a requirement. The first 20V parts produced using a new manufacturing process, the FDS6572A/6574A feature lower RDS(on) in the same or smaller die size as common 30V devices. Low threshold voltage is 0.6V for the FDS6574A and 0.8V for the FDS6572A which allows low RDS(on) to be achieved with low gate voltage.

According to the supplier this is important for secondary side regulators where the available gate drive voltage can actually be below the output voltage, which in some cases is as low as 1.5V. These SO-8 packaged devices offer RDS(on) for the FDS6574A of 9mΩ at 1.8V (VGS) and both parts specified at 6mΩ at 4.5V.

Fairchild
Tel: +44 (0)49 8141 61020
www.fairchildsemi.com

2.5kV solid-state relay is 5mm wide

Finder's first solid-state relay is a version of the company's 34-series electromechanical PCB-mounting part. Designated the 34.81, the relay is initially available in two models. One has the part-number suffix 9024 and is designed for switching up to 2A at 24V DC. Its partner — suffix 7048 - can switch up to 100mA but at 48V DC. Each can be specified for 24V or 60V DC control input. Featuring silent operation, the 34-series solidstate relay has a footprint of 28mm by 5mm and measures 15mm high. It mounts on the PCB via its...
2.4GHz spread-spectrum technology

AeroComm has published brochures which are intended to expose a number of what the 2.4GHz spread-spectrum wireless system supplier calls 'Wireless Myths'. Aimed at those involved with the selection, purchase or design of wireless systems for use in a wide range of OEM applications, the four literature pieces offer advice concerning equipment selection, standards, interoperability and approvals. For example, one brochure deals with the 802.11 standard which the company claims is somewhat erroneously known as the industry standard. Another looks at single frequency radios.

Finally, Bluetooth comes in for a pasting.

AeroComm
Tel: +44 (0)1908 326342
www.aerocomm.com

Channel device for DS3 access systems

TranSwitch has an IC plus software for next generation channelised DS3/DS1/E1/DS0 communications network applications targeting wireless access, multi-service access platforms, time division multiplexing (TDM) over packet, and echo cancellation. Called TEPro, it is a RISC processor-based device with embedded DD-AMPS firmware and host API supporting the requirements of next-generation channelised DS3 access systems. Supporting either one DS3, 28 DS1, or 21 E1 line interfaces, the device can be configured for different operating modes. It integrates an M13/G.747 multiplexer including a DS3 framer with full C-bit functionality to support clear-channel DS3; a 28-channel E1 framer, and a 28-channel DS1/E1 cross-connect.

TranSwitch
Tel: +44 (0)32 1680 7538
www.transwitch.com

CAN controller can be pre-qualified

Atmel has announced pre-qualification of its CANary microcontrollers for automotive temperature ranges. The devices implement self-programming code flash memory and data EEPROM. By executing the C51 code located in the boot flash memory, one can update the code or data in flash and EEPROM in-application, after system deployment. The changes may be handled either through the UART or the CAN bus or any tailored customer interface at any step of the end-product’s life cycle.

The CANary microcontrollers are available with different flash memory sizes and packages for diverse automotive applications. For embedded target applications, Atmel’s embedded CAN microcontrollers are fully compliant with specification levels 2.0A and 2.0B. Additionally, they can handle from 4 up to 15 message objects independently and dynamically assign them to the reception, transmission or reception buffers in case of multiple CAN frames. To complete the full capability line-up of the CAN product family, these devices also support a variety of possible secure applications by supporting industry requirements such as, for example, time triggering and time stamping.

Atmel
www.atmel.com

Cases for horizontal PCBs

The 1455 series of extruded aluminium instrument cases from Hammond Electronics are primarily designed to house PCBs, mounted horizontally into internal slots in the body of the case; they can also be used to house any small electronic, electrical or pneumatic components. The units are available with silver or black anodised finish for good resistance to wear and tear. Two types of end panels are available; either a flat aluminium panel, retained to the case body by a plastic bezel, or a one-piece moulded plastic panel. There are seven sizes in the family ranging from 80x54x23mm to 220x103x53mm; the two largest sizes have a removable cover on the case body to allow access to the PCB when it is in situ; these units will accept a standard 100x160mm or 100x220mm Eurocard respectively.

Hammond Electronics
Tel: +44 (0)1256 812812
www.hammondmfg.com

solder pins. Dielectric strength between the input and output of this relay is 2.5kV.

Finder
Tel: +44 (0)1785 818100
www.findernet.com

Programmable virtual button IC

Quantum Research Group has released a programmable touch sensor IC. The 8-pin part is based on the UK firm’s proprietary Qprox charge-transfer technology. It is based on a RISC processor core and has two sensing channels. It can be used to create ‘virtual buttons’ through glass, plastic, stone, ceramic, and even wood. It can also turn small objects into touch controls. The QT320 is designed specifically for human interfaces, for example in appliances, lighting controls, computer peripherals or anywhere a mechanical switch or button may be found. According to the supplier, the price per channel represents a 33 per cent reduction per sensing channel over its previous product family. The device uses signal processing techniques to tackle ‘stuck
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TYING THE KNOT

This month sees the practical implementation of Jeff Macualay's ideas of a full range motional feedback speaker system

Last month I described how, by using the back emf generated by a speaker and a dose of positive feedback, the Q of the bass resonance could be reduced. I also explained the relationship between this idea and standard T/S design theory. Now it's time to roll up my sleeves and produce a design based on this principle. Before doing so however I must discuss the influence of the voice coil inductance upon the performance of such speaker systems.

As you would have noted from the equivalent electrical circuit of a speaker shown in last month's sidebar, the voice coil inductance is in series with the tuned circuit equivalent of the bass resonance. Like the voice coil resistance, this inductance is not constant but varies with the voice coil's position in the gap. It has an influence on the high frequency response of a driver because it forms a series resonant circuit with the reactive components representing the bass resonance. If this is not compensated for in the circuit it will seriously reduce the bandwidth of the system.

The cure is to place a small proportionally sized inductance in series with the sense resistor in the positive feedback circuit. This appears as a negative inductance at the amplifier's output, thus cancelling the voice coil's inductive effect on the circuit. The net effect is to restore a flat overall frequency response to the circuit.

In order to design a successful speaker system we must first define what the objectives are, in other words a specification. In this case I want to produce a small to medium sized monitor speaker capable of 25Hz - 3kHz. Of course, just as much attention must be paid to the entire frequency range as well as just the bass. As I have to design a modified power amp for the bass section, it makes sense to make the design active and self contained. In this way you only need a signal source and you have a complete audio system. These thoughts lead naturally towards the first design choice, which drivers to use.

For good bass output a large diameter driver with good linear excursion range is indicated. Unfortunately 12" drivers, the logical choice, have a limited piston range and tend to die above 1kHz or so, making crossover design difficult. Just as importantly a wide cabinet would be required leading to poor horizontal sound dispersion and stereo imaging problems. The choice made here is to use a pair of 8" drivers in parallel. These have as great a radiating area as a 12" speaker but fit into a slimmer enclosure. In addition they provide an extra 6dB worth of acoustic output, compared to a single driver.

As far as the tweeter is concerned I have chosen to use a Morel MDT29. This is a high quality soft dome unit with a very smooth extended response, high power handling and a low resonant frequency. After perusing a few catalogues and some further thought the bass units chosen were the Morel MW265. These 8" drivers were chosen for their 8mm pk-pk excursion and flat response in the midrange.

Having decided upon the drivers the design work can commence. First to be determined is the required enclosure volume and this means choosing the power amp rating. Since we are designing a domestic system a peak output of 104dB/W/m was designed for. If my neighbours are to be believed this is more than enough output. With a 88dB/W/m sensitivity per driver this is not an arduous task. Two drivers connected in parallel will give 94dB/W/m so the power amp needs an power output of 10db. This works out at 20 watts into 4Ω.

This is convenient because the output amps can be designed around op-amps working at normal supply voltages. Since the rest of the circuitry is op-amp based the circuit can be implemented fairly easily.

Having chosen the drivers the next task was to determine the enclosure size. Using the data sheet information and the method outlined in my previous article this was computed to be 26 litres.

As I had decided to use two woofers, the dimensions of the cabinet were dictated by the need to mount all three drivers on the front panel. I chose to use the MTM (Mid-Top-Mid) layout. This configuration has been used to circumvent phase shifts in odd order crossovers and is popular in the US where it is known as the 'D'Appollito' configuration.

The design was started by building a prototype enclosure and measuring the frequency response of the drivers in situ. Figure 1 shows the nearfield response of the MW265. This is measured with a microphone mounted a few millimetres from the cone. No signal gating is used. The response clearly shows the bass resonant peak and rolloff. Measuring the impedance curve showed that the system was operating as a hi-pass 2nd order filter with a turnover

Figure 1: MW265 nearfield response
frequency of 80Hz. This was in accordance with initial T/S calculations.

Next, the speaker was driven from an amplifier modified to give a negative output impedance of ~2.1Ω. This was the value calculated to reduce the bass resonant Q to 0.4. Figure 2 shows the resulting near-field measurement. As you can see, the bass resonant peak has been suppressed but the response resembles that of a band-pass filter centred around 200Hz. This is, of course due to the voice coil inductance resonating with the moving mass as described earlier.

When considering this project I had in mind an active speaker with separate amplifier channels for the woofer and tweeter fed from an active 4th order crossover network. Consequently I set to work breadboarding the necessary circuitry. After a fortnight of work on the project it became clear to me that there must be an easier way. I ended up with 4 quad op-amps per channel. Although it sounded fine it was difficult to obtain a flat enough measured response. At this point I went back to basics. Why not forget about the crossover unit and concentrate on simplicity?

Let me explain. Crossover units are more of a necessary evil than anything else. Even the best of them introduce excessive phase shift that tends to ruin the stereo image. This is especially true around the crossover frequency, as this is usually between 1 and 3kHz. slap bang in the middle of the vocal range, where the ear is at its most sensitive. Only first order crossovers are free from this defect. Unfortunately the frequency range of the drivers needs to be extremely wide for such a crossover to be viable.

The other problem hardly ever addressed in crossover design is the natural rolloff and phase shift introduced by the drivers themselves. Interestingly, the easiest way to minimise phase shift problems is to use crossovers with a large overlap region. That is to allow both drivers to radiate together over an extended range. It was with these thoughts in mind that I looked again at the overall response of the system without a crossover.

The response of the unequalised system rises at 6dB/octave below 2kHz, levelling out at 200Hz before falling in the bass. However most of the woofer’s response irregularities have been smoothed out by the applied motion control feedback. I reasoned that the response could be rendered sensibly flat by a simple shelving filter. After some breadboarding, a response within ±4dB between 100Hz and 18kHz was obtained. Figure 3 shows the overall response obtained by the equalised system.

More importantly what was the sound was now right. Unless you knew better you wouldn’t believe that there was no crossover unit. Some might question whether the dome tweeter would be capable of handling the power. Well, the tweeter itself does a good job of rejecting low frequencies as its response drops at 12dB/octave below 900Hz. The addition of a series 10µF capacitor adequately protects this driver from low frequencies. In fact the acoustic response of the driver/cap combination is >60dB down at 100Hz. I didn’t bother to include the tweeter in the mechanical feedback loop though. There are two reasons for this. First, the acoustic response of the tweeter is that of a critically damped second order hi-pass filter. There would be no advantage in reducing the Q even more.

Secondly, the driver tweeter would effectively damp out the impedance of the woofers leading to unpredictable results.

However, the use of a full range speaker system without crossover is not unique. I would like to quote P.J.Baxendall's 1968 Wireless World article, 'Low Cost High Quality Loudspeaker' as an inspiration for this system. In the above mentioned article the author described using equalisation to a small full range driver to obtain a 100Hz to 15kHz flat response. The equaliser consisted of a pair of closely coupled LC circuits. These days op-amps are ubiquitous and very complex transfer functions can be simply obtained by their use.

The bass response was equalised with a separate circuit. The full circuit is shown in Figure 4a. Here input signals, at line level, are fed into the non-inverting input of A1 via the volume control VR1. A1 is used as a low gain buffer to provide a low impedance drive for the active filter circuitry. The shelf filtering is done with a passive network comprising C1,R3,R4 and R5. From here the signal is fed into the bass equaliser circuitry built around A2. This equaliser is half passive half active. It consists basically of two near identical low pass, first order filters. The passive part consists of R6, C2 and R9. The signal from the output of the filter is then taken directly to the non-inverting input of A2. The active part of the filter comprises C3,R7 and R8. Both these sections boost the bass response in the 10-40Hz range.

The next stage of the bass equalisation consists of the shunt feedback amplifier built around A3. This applies gentle bass boost between 50-200Hz. The filter consists of C4,R11 and R12. The gain of the circuit, about 6.5dB and the gain of the A1 stage, are necessary to compensate the insertion loss associated with the passive filter sections. Finally the bass response below 20Hz is deliberately curtailed by the hi-pass filter comprising C5,C6,R13 and R14. If this isn't done valuable cone excursion could be wasted unnecessarily, excursion that could be more usefully employed generating bass! The response of the equalisation circuit is the

Figure 2: MW265 nearfield response # -2.1R

Figure 3: Overall system frequency response
mirror image of the un-equalised acoustic response. Obviously when the two responses are combined result is a flat system response. Figure 5 shows the overall response of the equaliser.

Attention can now be turned to the amplifier, speaker feedback circuit. This is shown in Figure 4b. The power amp needs to provide a low distortion signal of wide bandwidth to the drivers. The easiest way to produce such an amplifier is to use the brains-brawn op-amp technique. The op-amp, A5 provides the 'brain' part of the circuit whilst the brains is provided by the output stage. Specifically the input signals, supplied from the output of A4 are fed directly to the non-inverting input of A5. The output from A5 is applied to the output stage via the biasing network. This comprises a Vbe multiplier, Q1, PR, R23 and the biasing resistor R17.

The output stage proper comprises a pair of discrete complementary Darlington pairs. Q2 and Q4 comprise the NPN Darlington and Q3 and Q5 the PNP Darlington. Plastic power transistors are used both to simplify mounting and allow easy mounting of Q1. To remove the possibility of thermal runaway, Q1 is mounted directly on the mounting tab of Q4. R18 and R19 are also incorporated to provide linearisation of the output stage at low signal levels.

Overall negative feedback is applied around the circuit by R16 and R15. C9 acts as an open circuit to dc whilst passing ac signals. The amplifier’s output is thus stabilised by 100% dc feedback through R16.

Tweeter signals are ac coupled via the 10uF cap C10 whilst the wooferes are connected in parallel to the junction of R18 and R19. Signal current through the wooferes is sampled as a voltage drop across R20. A6 is used as an inverting amplifier that phase shifts the signals across R20 by 180° to provide a positive feedback signal. Positive and negative feedback signals are mixed together at A5’s inverting input via C9, R15 and R16. The amplifier as a whole produces < 0.01% THD at 1kHz and at any level below clipping. Note that the drivers are connected in reverse polarity to compensate for the phase inversion caused by A3.

Finally the PSU. This is shown in Figure 4c.
and is very conventional. The mains voltage is stepped down by T1, full wave rectified by the bridge, BR1. The resulting ± supplies are smoothed by C11 to C12. Parallel capacitors were chosen since they are easier to obtain than 10,000µF types and are somewhat smaller. Stabilised power supplies are used for the equaliser circuit. Voltage regulators IC2 and IC3, de-coupled by C7 and C8 providing the necessary rail voltages.

Having described the circuit operation attention can be turned to the construction of the system. Assembling the circuit requires little comment. As long as the polarised components are correctly orientated no problems should result. Before applying power though it is important to ensure that PR1 is turned fully anticlockwise so that the base and collector of Q1 are shorted together. Naturally the power transistors need to be mounted on a heatsink in the normal way with insulating washers and mica bushes. The heatsink need to be of the 'flat' type rated at 2°C/W or less so that it can be mounted flush with the enclosure rear panel. Note also that Q1 needs to be mounted on the heatsink in a similar way.

**Component list**

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<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Quantity</th>
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The prototype enclosure was built from 15mm thick melamine faced chipboard although there is no reason that equal thickness MDF couldn’t be used. The mechanical details are shown in Figure 6. It’s a good idea to get your timber merchant to cut it to size. There’s nothing worse than trying to make enclosures with wrong sized pieces! The main requirement of the enclosures is that they are airtight when assembled. Epoxy rapid is a excellent glue for this purpose. However, it pays to run some interior Polyfilla down the seams to be sure. You will notice that the enclosures contain nothing more complicated than butt joints. This is deliberate. I hate woodwork and there is a requirement to make the back panel removable to allow mounting of the electronics. Notice the integral partition behind the tweeter cut-out. Don’t fit this at this stage.

Having glued and screwed the front and sides together the drivers can be mounted. A jigsaw makes short work of this. To ensure an airtight fit, the drivers need to be mounted on a sealing gasket. A strip of draught excluder foam strip is ideal for this purpose. For the speaker wiring nothing exotic is required. 5A domestic mains lead is more than adequate, especially as a length of 50cm on each driver will be ample.

Now the internal partition. This is necessary to stiffen the cabinet and thus eliminate panel resonances. A recess needs to be cut behind the tweeter aperture to avoid fouling it. The dimensions here are not critical. Glue the partition into place.

Now the assembled electronics can be mounted on the back panel. A slot will need to be cut to accommodate the heatsink which is screwed to the outside. Having mounted the electronics on the panel the quiescent current can be set. For your own safety at this stage I would suggest that you bind any live terminals with insulating tape. The quiescent current is set by monitoring the voltage drop across the emitter resistors R18 and R19. First connect the drivers, adjust VR1 to minimum and switch on. Nothing should happen. If you get a loud hum you have a fault, switch off immediately and rectify. Assuming all is well, monitor the voltage drop between Q4 and Q5 emitters whilst slowly adjusting PR1 clockwise. Set this voltage between 10-20mV using a multimeter. Apply a signal to the input and advance VR1. Undistorted sound should emanate from your speaker. All that remains is to fit the rear panel.

In order to do this proceed as follows. Temporarily tape the rear panel in place with masking tape. Drill 3mm holes around the periphery of the panel into the assembled cabinet. Countersink the holes. Remove the tape and insert some foam strip between the surfaces to ensure an airtight seal. Screw the back panel into place with some 25mm, No 8 ST screws. You now have a functioning system.

As a final note I would recommend this system to any hi-fi enthusiast who likes constructing their own gear. The combination of motional feedback and the lack of crossover give an excellent transient response. Bass is solid and extended and the stereo imaging is three dimensional with good recordings.
Building on last month’s discussion of single-slope, single-breakpoint non-linear foldback limiting, this next section covers a dual-slope alternative.

Introducing a resistor, $R_d$, in series with the diode in Fig. 27 causes the voltage drop across the series combination to increase linearly above the diode’s conduction threshold. In turn, this induces a net linear increase in potential across the voltage divider $R_{2A}$ and $R_{2B}$. This gives rise to segment B-D in the protection locus, Fig. 26, whose gradient can be varied linearly with $R_d$ about point B. This allows greater flexibility with regard to optimal placement of the breakpoint. For brevity the essential diodes $D_F$ and $D_P$ described in part 1 of this paper are omitted in all subsequent figures.

As is the case with single-slope, linear foldback limiting, segment B-D must intersect the safe operating area’s $V_{ee}$ axis at a value greater than the sum of the moduli of the supply rails, if spurious limiter activation is to be prevented. Available current per output pair at $V_{ee}$=4V, is further increased to 12A8 compared to 7A1 for the locus in Fig. 13.

Initially, resistor values without $R_d$ are calculated for segment A-B-C, Figs 28, 29, and the value of $R_d$ established in situ, Fig. 30, using any convenient set of points along B-D.

With reference to Fig. 28, and selecting $R_1$=8K2:

$$I_d = I_1 + I_2 + I_3 \quad \text{(10)}$$

And,

$$R_{2A} = \frac{0.6}{0.88} R_{3A} \quad \text{(11)}$$

From equation 10:

$$I_d = \frac{40 - 4.6}{8k2} \text{mA} + \frac{0.88}{R_{3A}} + \frac{0.6}{R_1} \quad \text{(12)}$$

From Fig. 29, and invoking equation 11:

$$0.6 = \frac{3.08R_{3A}(0.6/0.88)}{R_{2A}(0.6/0.88) + R_{3A} + 8K2R_d/(8K2 + R_1)} \quad \text{(13)}$$

Solving (12), and (13), simultaneously:

$$R_1 = 704R7,$$

$$R_{3A} = 356R9.$$  

And,

$$R_{2A} = (0.6/0.88)R_{3A} = 243R3.$$  

With reference to Fig. 30:

$$I_1 = (0.6/R_{3A}) = (0.6/243R3) = 2.47mA$$

$$V_1 = (I_1R_{2A} - 39V4) = -38V52$$

$$V_{3A} = (V_1 + 39V89) = 1V37$$

$$I_1 = (V_{3A}/R_1) = 1.94mA$$

But,

$$I_2 = I_1 - (I_1 + I_3) \quad \text{(14)}$$

Where,

$$I_1 = (40 - V_{ee})/8K2 = 9.58mA$$

$$I_2 = 9.58mA - (2.47mA + 1.94mA) = 5.17mA$$
It is worth considering that the forward voltage drop, \( V_f \), is around 0.6V when \( I_d \) is about a milliamp for most small signal diodes at 27°C. For a suitable device though, such as the 1N4148, \( V_f \) is around 0.65V when \( I_d \) is 5mA. This requires that \( R_d \) calculated above be revised downwards.

\[ R_d = \left( \frac{V_{ps}}{I_d} \right) - (V_f - 0.6) = 149 \, R_1. \]

As previously recommended, the calculated resistor values should be made up from series, and/or parallel combinations of 1% components where necessary.

The dual-slope, single-breakpoint scheme in Fig. 31, sometimes erroneously described as 'treble slope', is an amalgam of the circuits in Figs 5 and 18. As in Fig. 18, the breakpoint occurs at \( V_{out}=0 \), i.e. \( V_{out} = V_{cc} \), giving locus A-D-E-F. Fig. 32. However, segment D-E-F, being part of C-D-E-F, is established by \( R_1 \) and \( R_3 \). As a result, its efficacy is therefore dependent on the value of \( R_d \) as the network in Fig. 5.

Resistor \( R_2 \) merely pulls the base of the protection transistor low as required for \( 0 \leq V_{cc} < 40 \text{V} \). This gives segment A-D, whose position in the safe operating area is for enhanced precision. Thus,

\[ R_d = \left( \frac{V_{ps}}{I_d} \right) - (V_f - 0.65) = 139 \, R_3 \]

**Figure 27:** Dual slope, single breakpoint, non-linear foldback limiter

**Figure 28:** Output conditions at point B on the protection locus in figure 26

**Figure 29:** Output conditions at point A on the locus in figure 26

**Figure 30:** Output conditions at point D on the locus in figure 26
Figure 31: This dual slope single breakpoint scheme is a logical development of the circuits in figures 5, and 18.

Figure 32: Dual slope single breakpoint loci described by the circuits in figure 31 and 35.

Figure 33: Output conditions at point F on locus A-D-E-F of figure 32.

Figure 34: Output conditions at point A on locus A-D-E-F of figure 32.

Figure 35: Efficacy of the compromised dual slope scheme of figure 31 is improved by using arbitrary, bootstrapped voltage references of equal magnitude.

Figure 36: The reference voltage is made equal in magnitude to the output voltage at the breakpoint, (i.e., when $V_{ce}=56$V); the diode is then at the threshold of conduction.
ill-defined for non-ideal supply rails, due to the use of an invariant voltage reference.

Since the breakpoint for this arrangement is fixed at \( V_{cc} = V_{cc} \), only points A and F on locus A-D-E-F are required to obtain a solution.

With reference to Fig. 33, let \( R_3 = 220R \) and \( V_{cc} = 40V \):

\[
I_s = I_3
\]

Where,

\[
I_s = \frac{-39.4 + 39.78}{220R} = 1.73mA
\]

and,

\[
R_3 = \frac{40 + 39.4}{1.73mA} = 46K
\]

With reference to Fig. 34:

\[
I_s = \frac{40 - 37.52}{(R_1 / R_3)} = 2.48/219R = 11.33mA
\]

With \( V_{ref} = 0V7 \) at 11mA,

\[
R_3 = \frac{V_{ref}}{I_s} = \frac{37.52 - 0.7}{11.33mA} = 3K3
\]

This scheme is clearly inferior to the standard linear foldback arrangement of Fig. 1. It delivers only 1A5 at \( V_{cc} = 45V97 \), requiring a minimum of six output pairs for \( 42 \pm 60^\circ \) load drive from \( \pm 40V \) supply rails.

As in Fig. 22, the network in Fig. 31 can be usefully improved, Fig. 35, by changing the diode reference from zero to an arbitrary voltage, \( V_{ref} \), such that, 0V<\( V_{ref} < V_{cc} \).

This enhances the flexibility of the circuit, as the breakpoint can now be moved freely along segment C-F. This gives rise to a more efficient locus, B-E-F, Fig. 32, whose position in the safe operating area is unaffected by supply rail variation.

The reference voltage is established by determining the output conditions at the breakpoint, Fig. 36. Therefore for locus B-E-F in Fig. 32, \( V_{ref} = -16V33 \) and \( V_{ref} = +16V33 \). This calls for a nominal 56V33 zener diode. As previously recommended, multiple low-voltage devices should be used to minimise series impedance.

With reference to Fig. 37:

\[
I_3 = I_i
\]

Where,

\[
I_i = \frac{-39.4 + 39.78}{220R} = 1.73mA
\]

\[
R_i = \frac{40 + 39.4}{1.73mA} = 46K
\]

Referring to Fig. 38:

\[
I_s = \frac{40 - 38.4}{(R_1 / R_3)} = 1.6/219R0 = 7.3mA
\]

With \( V_{ref} = 0V65 \) at 7mA,

\[
R_3 = \frac{V_{ref}}{I_s} = \frac{38.4 - 0.65 + 16.33}{7.3mA} = 7K4
\]

Note that there is no change in the value of \( R_i \) and \( R_3 \) in the circuits of Figs 5, 31, and 35, with different values of \( R_3 \) required to merely pull the base of the protection transistor low as appropriate when the series diode is forward biased.

Although the efficacy of the protection locus is in part ameliorated by the means described above, for the gradient of segment E-F, being part of C-D-E-F, is determined by resistors \( R_1, R_3 \), and limited by practical values of \( R_3 \) - an affliction absent in the circuit of Fig. 27.

Complete independence from \( R_3 \) of both segments of the dual slope protection locus described by the circuit in Fig. 35 can be accomplished by the introduction of a base-emitter resistor, \( R_5 \), Fig. 39, for each protection transistor. The result is in fact merely a union of the linear single slope scheme of Fig. 1, and the non-linear single slope circuit of Fig. 22.

The linear single slope locus in Fig. 2 is reproduced in

---

**Figure 37:** Output conditions at point F on the protection locus in figure 32.

**Figure 38:** Output conditions at point B on the protection locus in figure 32.

**Figure 39:** Introducing resistor \( R_5 \) into the circuit of figure 35 permits placement of an arbitrary locus in the S.O.A., without undue dependence on the value of \( R_3 \).
Figure 40: Dual slope, single breakpoint locus described by the circuit of figure 39. Resistor \( R_4 \) modifies the linear single slope segment B-C-D, of figure 2 by effecting a vertical translation of segment B-C about point C.

Figure 41: Output conditions at point A on protection locus A-C-D in figure 40.

Fig. 40 as segment B-C-D, for which equations (1) and (3) are valid. So, referring to Fig. 41, with \( R_3=220 \Omega \), then \( R_1=12 \text{K} \Omega \) and \( R_2=143 \Omega \). Resistor \( R_1 \) pulls the base of the protection transistor low as required for \( 0 \leq V_{\text{ce}} \leq 42 \text{V} \), giving segment A-C.

The reference voltage is equal to the output voltage when \( V_{\text{ce}}=42 \text{V} \), thus,

\[
V_{\text{Ref}}=40 \text{V}-(42 \text{V}+(3.45 \times 0 \text{R}22))=2 \text{V}77.
\]

and \( V_{\text{Ref}2}=2 \text{V}77 \).

Referring to Fig. 41:

\[
(I_1+I_2)=(I_1+I_3)
\]

\[
I_4=(I_1+I_3-I_2)
\]

\[
I_3=(40-37.96)/12 \text{K}+143 \text{R}-0.6/143 \text{R}
\]

\[
I_3=5.24 \text{mA}
\]

With \( V\equiv0 \text{V}6 \),

\[
R_1=V_{\text{Ref}}/I_3=(37.96-0.6+2.77)/5.24 \text{mA}
\]

\[
R_1=7 \text{K}7
\]

The flexibility of the scheme in Fig. 39 is significantly improved relative to Fig. 35. However such flexibility is easily surpassed by the network in Fig. 27, whose accuracy is not compromised by dependence on discreet value zener references.

**Treble-slope, (dual-breakpoint) non-linear foldback limiting**

With modern power transistors and practical loudspeaker systems, an optimally located dual-slope protection locus realised by the limiter in Fig. 27 can hardly be improved upon with respect to efficiency in the critical \( 1V_{\text{ce}} \leq V_{\text{ce}} < 21V_{\text{ce}} \) region.

However, for purely resistive laboratory loads with which a power amplifier’s published specifications are obtained, the \( 0V \leq V_{\text{ce}} \leq 2V_{\text{ce}} \) region of the safe operating area is of primary interest, Fig. 10.

In a competitive market place therefore, even when the truth of the matter is known, an amplifier designed to maintain its rated voltage swing across resistive loads of decreasing magnitude – down to \( 1 \Omega \) – without limiter intrusion, may be commercially rewarding. A suitably robust power supply and conservative thermal
management are assumed.

To this end the treble-slope design in Fig. 42 is presented. The circuit is a straightforward amalgam of the dual-slope scheme of Fig. 27, and the single slope, single breakpoint network of Fig. 22.

The circuit in Fig. 27 produces the dual slope characteristic B-D-F. Fig. 43, while resistor $R_4$ pulls the base of the protection transistor low as appropriate for $0 \leq V_{ae} \leq 42$V, giving segment A-C. Fifty-volt supply rails are assumed; a treble-slope locus with ±40V rails is vastly unnecessary.

The reference voltage is equal in magnitude to the output voltage $V_{out}$ at breakpoint C, Fig. 43. Thus,

$$V_{ref|1} = V_{ref|2} = V_{out|1} = 7V_{23}$$

with $V_{ref}$ at $7V_{23}$ and $V_{ref|C}$ at $-7V_{23}$.

As previously established for Fig. 27, component values without $R_d$ are calculated for segment B-D-E (Figs 44 and 45), and the value of $R_2$ established in situ, Fig. 46, using any convenient set of points along D-F. Resistor $R_4$ is then calculated for a nominal $V_{ee}=0$V, at point A, Fig. 47.

With reference to Fig. 44, let $R_1=8K2$, and $V_{ee}=0$V6 when $I_a=1$ m A.

$$I_a = I_1 + I_2 + I_3$$

And,

$$R_{2|a} = (\frac{0.6}{0.44}) R_{2A}$$

From equation 15:

$$\left(\frac{50 + 11.4}{8K2}\right) = 1mA + \frac{0.44}{R_{2A}} + \frac{0.6}{R_2}$$

From Fig. 45, and invoking equation 16:

$$0.6 = 1.474 R_{2A} \left(\frac{0.6}{0.44}\right) R_{2A} + \frac{0.6}{R_2} + \frac{0.6}{R_3} + 8K2 R_{2A} (8K2 + R_3)$$

Solving (17) and (18) simultaneously:

$$R_2 = 160R7$$

$V_{ref|1} = 159R8$

$$R_{2|a} = (0.6/0.44) R_{2A} = 217R9$$

With reference to Fig. 46:

$$I_a = (0.6/R_1) = (0.6/217R9) = 2.75mA$$

$$V_e = (I_a R_4 - 49V4) = -48V96$$

$$V_{bs} = (V_e + 49V89) = 0V93$$

Figure 43: Treble slope, dual breakpoint protection locus described by the circuit of figure 42, Resistor $R_4$ modifies the dual slope characteristic B-D-F by effecting a vertical translation of segment B-C about point C.

Figure 44: Output conditions at point D on characteristic B-D-E in figure 43.

Figure 45: Output conditions at point B on characteristic B-D-E in figure 43.
But,

\[ I_s = I_i - (I_1 + I_3) \]

Where,

\[ I_i = (40 - V_x)/8k2 = 10.85mA. \]
\[ I_s = 10.85mA - (2.75mA + 5.79mA) = 2.31mA. \]
\[ R_s = (V_{in}/I_s) = (V_{in} - 0.6)/I_s = 143\Omega \]

From Fig. 47:

\[ R_s = (V_{in}/I_s) \]

Where:

\[ I_s = I_{sA} - I_{sB} \]

\[ I_s = \frac{(50 - 47.96)}{(R_s/\theta_1 + R_s/\theta_2)} = 3.67mA \]

\[ R_s = (47.96 - 7.23 - 0.6)/3.67mA = 10k\Omega \]

A 4Ω±60° load driven to ±50V rails requires \( i_s = 4.45 \) when \( v_{in} = 59V \), resulting in peak transistor dissipation, \( P_{diss} = 561W \). The treble slope protection locus of Fig. 43 allows 2A at \( v_{in} = 59V \) for a single complementary transistor pair. Therefore, five complementary pairs are required to drive a notional 4Ω±60° loudspeaker system from ±50V supply rails without intrusive limiter activation.

The required reference voltage calls for a nominal 42V77 voltage drop across \( Z_1 \) and \( Z_2 \). As previously recommended, the required voltage drop should be realised with multiple low-voltage devices, of 6V to 12V, as a series combination of these should collectively possess a significantly lower series impedance than a single high voltage device.

In practice, \( Z_1 \) and \( Z_2 \) may each consist of five ZPD6.8RL, in series with a single ZPD8.2RL, biased at a nominal quiescent current of 10mA by \( R_c \).

A more elegant – if rather tedious – approach² compensates for variation in zener voltage drop with temperature. This calls for the introduction of typically two to four forward biased diodes in series with the zener diode.

The decreasing voltage of the forward biased p-n junctions with increasing temperature, (negative temperature coefficient), tends to counteract the increase in zener voltage with increasing temperature, (positive temperature coefficient), and conversely. Therefore \( Z_1 \) and \( Z_2 \) may each consist of a series combination of three IN961B 10V zeners, a single ZPD8.2RL 8.2V device, and seven 1N4148 forward biased diodes.

For brevity perhaps, in place of \( Z_1 \) and \( Z_2 \), the shunt-feedback circuit of Fig. 48 may be used with a single, temperature compensated zener reference diode, such as the 6.2V 1N829A. This circuit permits the synthesis of a high voltage source without recourse to loose-tolerance, high voltage zener diodes, or indeed multiple small-value devices.

However, the variation in zener voltage drop due to

\[ Y_{drop} = (V_x + V_{be})(R_1 + R_2)/R_2 \]

Figure: 46. Output conditions at point F on dual-slope characteristic B-D-F of figure 43.

Figure: 47. Output conditions at point A on treble-slope protection locus, A-C-D-F, of figure 43.

Figure: 48. Shunt feedback voltage generator may be used in place of \( Z_1 \) and \( Z_2 \) to circumvent the tedious of selecting multiple diodes.
current fluctuation is invariably more significant than that due to change in temperature. Where cost is no object, $R_2$ may be replaced with a temperature compensated\textsuperscript{22} current source/sink, Fig. 49. This can be in the guise of a LED-biased transistor, $T_c$.

LED current limiting resistor $R_e$ is split symmetrically into two components, $R_{c1}$ and $R_{c2}$ whose intersection\textsuperscript{4} is decoupled by capacitor $C_{filter}$ to the supply rail. The single-pole filter comprising $C_{filter}$ and $R_{c1}$ across the LED’s internal resistance, in series with $R_{c2}$, improves the regulation of the voltage drop across the LED by diminishing power supply ripple in the current established by $R_{c1}$ and $R_{c2}$.

A time constant, $\tau_{filter}=C_{filter}R_{c1}$, of the order of two seconds is sufficient. Connecting $C_{filter}$ directly across the LED is sub-optimal, as a commensurately larger component would then be required for the same time constant.

Resistor $R_e$ minimises power dissipation in $T_e$; a collector-emitter voltage drop of the order of 20V for a collector current of 10mA should suffice with suitable small signal transistors, such as Motorola’s 2N5551/2N5401.

**Protecting paralleled complementary output transistors**

Emitter resistor, $R_e$, performs current-voltage conversion for the V-I limiter. It also promotes thermal stability by maintaining equable current distribution in a paralleled pair output stage. For this reason some designers suggest\textsuperscript{5} that it is only necessary to monitor transistor current in a single complementary pair in a multiple-pair output stage.

Alternatively, the calculated value of the current sensing resistor, $R_s$, for a single complementary transistor pair is multiplied by the number of paralleled output pairs, $N$, with each resistor of value $NR_3$, used to monitor the current in each transistor, as shown in Fig. 50.

Note that using the non-linear limiter of Fig. 27 in this fashion requires that each resistor of value $NR_3$ be shunted by the diode in series with resistor, $R_d$, whose value remains unchanged.

An obvious disadvantage inherent in both schemes is that the failure of a rogue transistor in one half of the output stage could result in the disastrous alteration of the protection locus for the remaining devices in that section. With modern power transistors though, this...
As demonstrated in Fig. 26, the circuit's characteristic locus can be readily optimised to accommodate ±50V supply rails with MJL3281A/MJL1302A transistors. Higher supply rails are not recommended for worst-case reactive loads, as available collector current for these devices falls rapidly below 500mA with a $V_{CE}$ of more than 100V.

Although e-MOSFETs are at least an order of magnitude less linear than bipolar transistors\(^ {4, 273}\), they provide significantly greater scope for reliable design\(^ *\) at high device voltages, \((2V_{supply}) > 100V\), with the promise of even greater efficiency in S.O.A. utilization, due to the absence of secondary breakdown. However, there is no need to endure the indignity of e-MOSFET non-linearity and on resistance voltage inefficiency in sub-200W into 8Ω designs.

More elaborate protection schemes are possible, with the use of as many diodes as the number of required breakpoints. However the increase in available current in the high voltage region, \(I_{VCE} = 2V_{supply}\), where it counts with respect to reactive load drive, is negligible in relation to the circuit complexity thus engendered.

References
1. Duncan, B. 'High performance audio power amplifiers'. Newnes, ISBN 0-7506-2629-1. p. 202, and p. 204, Fig. 5.23, respectively.
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