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
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 follows 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.

- Measured signals and instrument settings can be saved on disk. This enables the creation of a library of measured signals. Text balloons can be added to a signal, for special comments.

- 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 60 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.x/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. 01480-460026, Fax 01480-460340.

- TiePie engineering (NL), Koperslagerstraat 37, 8601 WL SNEEK, The Netherlands.

- Tel +31515415416, Fax +31515418019

- Web: http://www.tiepie.nl

More enthusiastic readers

I am glad to see that you readers know what you want. Yet again the mailing 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 CGI-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 note 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 simulation 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 audiophile. What with the continuing of Cyril Bateam’s ‘Capacitor T&M’ which discusses the measurement of post loudspeaker cables, the concluding part of Michael Kowalski’s VI protection in audio amps and Jeff Macauly’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 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 EU 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 'PICAL' ISP PIC Programmer

Kit will program virtually ALL 8 to 40 pin" parallel and serial connected PIC microcontrollers. Connects to PIC parallel port. Supplied with fully functional pre-registered PICAL DOS and WINDOWS AVR Software packages, all components and high quality USB/COM board. Also programs ATMEAL AVR, ATMEAL SX and EEPROM 24C devices. New devices can be added to the software as they are released. Blanks chip auto detect feature for supported built-in programming. Hardware now supports ISP programming. *A 40 pin wide ZIF socket is required to program 027 devices. (Order Code AZIF27 @ £15.00).

Advanced 32-bit Schematic Capture and Simulation Visual Design Studio

ATMEAL 80xxx 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 8051 compatible computer and operating system. 16 LEDs indicate programming status. Programs 89C1051, 80C3051, 89C5051, 89C51, 89C51, 89C52, 89LV52, 89C52, 89S52, 89S52, 89S52, 89S52, 89S52, 89S52, 89S52, 89S52, 89S52, 89S52. NO special software needed - uses any terminal emulator program (Built into Windows).

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: providing input/output, external switch input, sensing, contact closure and external voltage sensing. Programmed via a computer serial port, it is compatible with ANY computer or operating system. After programming, PC can be disconnected. Serial cable can be up to 35m long, allowing remote control. User can easily write batch file programs to control the kit using simple text commands. NO special software required - uses any terminal emulator program (built into Windows). Screw terminal block connections. All components provided including a plastic case with pre-punched and silk screened frontpanel to give a professional and attractive finish (see photo).
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 Bries has 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. Bries 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, Bries believes.

Matlab gets speed boost

The Mathworkas, 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 Mathworks. “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 Mathworks 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.

Surrey Satellite to use Russian rockets

Surrey Satellite Technology and Rosoboronexport of Russia have signed a contract to launch 8 microsatellites from the Plesetsk Cosmodrome during 2002-2004. “Cosmos and REB 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 launched by SSTL in its first launch for SSTL, carrying the first EMC microsatellite ASAT 1, scheduled for autumn 2002.
Plastic chips get university backing
Polymers 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.

Besides 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 Epim, 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 brings together 90 per cent of the academics working in the UK in the field, including Sir Harry Kroto, whose team discovered C60, or buckyballs.

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 the 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 (LPPA) 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 by now," said Mike Brooks, chairman of the LPPA. "Yet everybody's using this is that 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 Brooks. 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 Brooks. "So we've got another hole being ploughed right through the SRD allocation."

Brooks is particularly worried by the Government's spectrum review which is opening the way for this to happen. He believes the review in the `days should basically boil 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.

Brooks said the amount of test 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 everywhere. 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."

Sewing with Windows - and GameBoy
Sewing machine company Bernina is making it its aim to be "the first authentic sewing computer," said Max Schmid, president of the company's US arm.

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

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

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

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

Sewers amongst Electronics World readers may be interested that the Artista 200E is available in an embroidery field, averages 600 stitches per minute and offers one-screen pattern editing.

The first sewing machine with a computer? - Try Nintendo!
Bernina is claiming that it is "the first authentic computer", but Japanese company Nintendo got there first and has been making Nintendo GameBoy-based sewing machines for a while. Its range includes the Nayell (which is sold by Singer as its Inkz), Nnotto and N-Yell.

GameBoys have quite a following as embedded computers - more 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 a gameport.

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

www.devis.com/gb is a comprehensive site and www.semix.demen.co.uk/GameBoy/Gbms.htm includes a GameBoy digital oscilloscope.

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 in the Magneti Marelli engine management unit. This simplifies the wiring and reduces weight, the firm said.

Various sensors and electronics on the bike connect to the processor in either the dash or ECU, 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 180°C.

Smart whip saves horses?
In an attempt to quantify the amount of beating occurring during horse races, Dublin bookmaker Rep Cregan has invented The Register, a smart-ship.

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

Matlab from The MathWork 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.
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 400 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 your VSM system in affordable stages.
- ARES Lite PCB Layout also available.

**THE AMAZING TELEBOX**

Convert your colour monitor into a QUALITY COLOUR TV. TELEBOX is an easy to use, plug-in colour conversion electronics module to turn into a full size TV monitor. Included is a complete audio unit. TELEBOX is ideal for use with most 19" or larger screen computer monitors and will fit any TV monitor. TELEBOX will also be able to be used with most 19" or larger screen computer monitors and will fit any TV monitor.

**NEW TELEBOX MB model**

TELEBOX MB Model adds a full size PAL monitor output (CMOS). TV conversion in PAL mode: H800xV600, 1150 line (PAL D) or 1200 line (PAL M). The TELEBOX MB model is ideal for use with most 19" or larger screen computer monitors and will fit any TV monitor.

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Capacitor myths.
Many articles have been written about capacitor behaviour, mostly by authors having little knowledge of capacitor design and performance. As a result, many false capacitor myths have emerged.
I will try to relate some of these myths to facts:
1. Almost all ceramic capacitors distort.
2. Dielectric absorption causes smearing and compresses dynamic range.
3. Polypropylene is an inefficient material.
4. Capacitors are highly inductive at audio frequencies.
5. 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 10µF and smaller are measured using LCR meters, larger than 1µF are usually measured at 100Hz (see box Tang facult) Each capacitor is voltage proof tested to ensure reliable operation at rated voltage. Leakage currents or insulation resistance will be measured at the specified time interval or less. To expedite this time consuming measurement, leakage current 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 distortive 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 resistance losses. Invariably the LCR meter 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).

Soundcard FFT Software.
Measurments for my earlier articles used Pico 232 PCI. Many readers may wish to use a soundcard instead. A modern low cost PCI card with FFT software can produce similar results to the older card. I decided the best choice was the Spectra 'Plus232' software under Windows 9x/ME, compatible with the PCI/ISA slots.
When testing with my near perfect 1µF WP test capacitor, this network introduced no distortions. A new network was required. It was assembled using 1µF and 1µF WP capacitors with a paper disc.

Dielectric characteristics.
In essence, two major dielectric characteristics exist, polar and non-polar. By polar, I am not referring to an electrolytic capacitor, but to dielectric cross links 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

Figure 2: The figure 1 capacitor tested using 1kHz with 18 volt DC bias. Compared to its 0 volt bias test, second harmonic 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 line filtering blocking capacitors, couple the 1kHz test signal. The test capacitor output is fed to the pre-amplifier via a 1µF capacitor. A current limited 100kHz test signal may be input to the tops terminal, DC bias to bottom right.

Figure 1: YSP is a medium 'K' class 2 ceramic. Tested with two signals, 100Hz and 1kHz at 2 volts amplitude, with no bias network, it produces many new intermodulation distortion frequencies.
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 C0C multilayer capacitor measured just 0.00006%, Second harmonic was -128.5dB, the other levels remained as shown.

Ceramic capacitors.

'Class 1' 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 C0C. 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. 3.

Class 2 ceramics provide 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 1000nF 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 over 50 years, 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 ceramics are strongly polar and its capacitance varies with applied voltage and temperature. It exhibits an easily measured

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 offset 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 to its original uncharged 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.

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 2.2pF 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 2.2pF 250 volt version of the MKP capacitor would be fine. I already had a distortion tested sample of the Epcof (Siemens) equivalent, so I used that instead. Source impedance resistors, as used in the buffer amplifier, are added and connected to the AOT 'hot' pin using a short fly lead. Two 100kΩ charged/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 each side of the buffer. For avoiding overloading the soundcard input, the 100kHz/1kHz connections to the bias network should be completed before connecting the pre-amp output to the sound card.

Visit www.peakelec.co.uk to download the data sheets, user guides and copies of independent reviews.

You can pay using a cheque, postal order, credit or debit card and even pay securely online. Please contact us for overseas or volume orders - you will be pleasantly surprised!
Tank/ESR

Tank is used to describe capacitor quality. A textbook perfect capacitor has a phase angle of 0°, a phase angle deviation of 0°, a Tank of zero. Using a 6425 precision LCR meter, Tank 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 10kHz 1%, axial lead, extended foil and Polystyrene capacitor. Fig. 7

Some of the resistive losses which contribute to Tank are due to lead out wires and metal electrodes, so are relatively constant. Tank then increases with frequency. At 10kHz, Tank for this capacitor was measured at 0.00015 and just 0.003 at 100kHz.

In past years capacitor quality was sometimes described as a 'Q' value, the reciprocal of Tank. 'Q' for the above capacitor was 20,000 at 1kHz, 6,666 at 10kHz and 2,000 at 100kHz.

Tank 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.

In which case,

\[
\begin{align*}
\text{Tank} &= \text{reactive vector} \\
\text{ESR} &= \text{reactive vector}
\end{align*}
\]

This reactive vector is called ESR.

ESR = \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 0.862 for 1kHz, 1.662 for 10kHz and 0.082 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 Tank together with a proven measurement circuit was included in a previous description of the construction of an in-circuit meter. This meter was custom designed to identify good or bad PCB mounted electrolytic capacitors by measuring their Tank while in-circuit.

Figure 7: This now discontinued Philips extended foil/Polypropylene 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 0.6dB and distortion to 0.00007%. There was no visible intermodulation.

dielectric absorption, which increases with 'k' value. Popular Class 2 ceramics include the X7R, X5R, BX capacitor grades and the exceptionally high 'k' Z5U. 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 Polystyrene. Terephthalate (PET). 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 83°C and cannot be metalised 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 pF.

All other popular film dielectrics can be metalised. They can be used to produce small, low cost, metalised film capacitors having a limited current handling ability. Alternately, using film assemblies, they are produced to produce larger and higher cost capacitors for the same value and voltage. Foil and film capacitors survive large DC voltages relatively well. Fig. 9

AC currents, than metalised film types.

Metalised film capacitors rely on 'self-healing' to 'clear' minor insulation faults, so can be assembled using very thin films, their metalised 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 films 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 metalised. Film thinner than one micron can be used at 50 volt capacitors. It is polar with 0.5% dielectric absorption and a relatively high 0.5% tanδ. Capacitance and tanδ are strongly temperature and frequency dependent and with up to 3% capacitance change in two years, it has poor long term stability. A metallised PET capacitor rated for 100V 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 metalised film type.

In contrast, non-polar PP, has a very small dielectric absorption of 0.015% and a low tanδ of 0.03%. It has less tensile strength and is much more difficult to metalise. 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 high currents 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 highest amplitude. Dist ceramics use solder connections to a soldered, usually silver, electrode. Multi-layer 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 metalised film and many foil and film capacitors use a 'Schoep' metal spray end connection to connect the capacitor electrodes to the lead-out wires.

I have measured many metalised 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 directly to the lead out wires. This is exactly the time proven assembly used by a large maker of extended foil/Polypropylene (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.
Polyethylene 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, in short circuited to every other turn, no longer contributes any 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 10μF '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 economical, extended foil/PP showed a second harmonic, measured for the PP versions. Both types are easily available from mainstream distributors in value up to 1μF. Fig. 7, Fig. 8.

For low distortion capacitors up to 10μF, my personal choices would be CG 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 our tests is variable. I have some which are at least thirty years old with almost no measurable distortion. However, a small batch of 1μF 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 FK22 foil and Polycarbonate capacitors. Buyer has discerned production of Makrofol Polycarbonate film, so FK22 capacitor production may cease. No doubt because of the thicker PET film used, I have measured surprisingly low distortion when testing Wima 10μF 100 volt FK22 foil and PET capacitors. Results were almost as good as the FK2P foil and PP of Fig. 8. Tested with 30 volt DC bias, second harmonic distortion was only 2dB worse than for the PP capacitor. Unfortunately, this FK2S 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 10μF, low distortion, low cost capacitors are easily available, so I would avoid using metallised PET capacitors. For capacitance values above 10μF, the near perfect COG, foil/PS and foil/PP types are not easily available. Our best options for capacitance values from 10μF 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.
2 3PC Components part lists and assembly/user notes, these single sided FR4 boards have solder resist and component legends. The set of three boards costs £32.50.
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Budget T&M on a PC

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 loudspeakers 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 ultimately the tests did nothing but measure, by a roundabout route, the series impedance of the cable.

Even a lead connected to a dummy load produced several fascinating and rather daunting technical articles in Hi-Fi News which examined audio cables from a theoretical standpoint. Unfortuately, he didn't produce much in the way of measured evidence and what little there was proved nothing more than that signals travel through cables at a finite speed (typically 0.66c), 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, aidded 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 dispove it) and the test procedures outlined in the first and second issues of this set 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 not be, 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 desalabiising 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 multicone 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 tests 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 1kHz, 59kHz, 250kHz and 1300kHz. This was played through a Roland 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: Goertz M1 and Supra PLY 3.4. The Goerds have very high capacitance/low inductance, the Supra has 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 10dB 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, handpick 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 0dB, with no increase in actual resolution but a big increase in viewable resolution using the log scaling in the frequency analysers window, Figs 3 and 4. The little

Figure 1: Spectrum at speaker terminals with Goertz M1 cable in circuit.

Figure 2: As Fig. 1, with Supra PLY 3.4 in circuit.
outcrop of frequencies around 1kHz 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 1kHz seems to get us no further. To increase the usable resolution still further, I compressed the waveform to one-fifth its 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 by some noise 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-sampke to the maximum Cool Edit will support (2MHz), synchronise to the nearest 250ns and subtract one from the other. Having located (by ear) 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 kHz if you've recorded with a CD recorder) and 32-bit depth, and paste the signal into it, right-hand 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 'Analyze' 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 2MSPs, 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 cable from the other. Re-sample to 4kHz 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 main harmonics which being in random phase relative to the stimulus will not null. But what of the peaks around 175kHz? Return to the original files, bandpass around 175kHz, 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 voltage across the speaker terminals. Note that I have seen wattage drop to zero scrutiny, though. No audio does not exist of pure sinuosities but given arbitrary constraints in time one can represent it to arbitrary accuracy by sinuosities and it's a very well-proven system. As for signals not showing up, why should 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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Storm scope

I enjoyed reading Joe Carr's article on lightning in the July 2002 issue of Electronic Business World (EBW). The scope described in the article looks like a very interesting device for monitoring and recording lightning discharges as 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 that he performed himself. Franklin's actual experiment, written by Joseph Priestley, was in manuscript by Franklin, and presumably verified by him.

The kite had a "sharp pointed wire" attached, and the wire was to be flown "when a thunder-storm 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.

Priestly describes Franklin seeing the loose filaments of the kite string sticking out as they became charged and repelled one another. Franklin then investigated the nature of the discharge by bringing his knuckle near the metal key attached to the string. Carrying this flying key building up on the kite and string, rather than a terrestrial 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 realize that the reason 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 emphasizes 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 Borreillos
Portage, Michigan, U.S.A.

unwanted noise and several different means may possibly be solved by all the problems above, including voltage, circuit capacitance, or latest and can be a very difficult problem to cure. Several years ago I worked for a then well known electronics test equipment manufacturer. They were part of what was then IBM. Back was scarce they took on an order for traffic control systems including the Pelican system. These units were being used in Europe and were being exchanged if the board could be fixed then and easier than a point-to-point assembly. So several dozen of these were made up and fitted. The meters were used to control the various previously existing units were now reporting stray errors. The output of this was that signals that had been passing without coupling now had plenty of way to do this. The units had to be completely rewired as before a point-to-point basis. This shows that noise testing does not lend itself to using greenhorns. It finally scuppered the whole order because of the extra cost and work that it took to change back to the correct layout. In fact it looks what wrong is in fact correct, I know from experience that you can always improve on an idea. The wheel still works well for me.

By email

LETTERS to the editor

Letters to "Electronics World" Highbury Business Communications, 19 Rosemary Road, Chaunc Sorrel, Surrey SM3 3BZ. E-mail: jow@highburybiz.com using subject heading 'letters'.

EMC

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

The basic idea, as most readers will know, is to limit earth currents from intersecting, 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 were there is no earth loop input stage. In this case the low power input, and the much higher output power must appear. 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 such interference, and can provide a ground plane here would be good to provide 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 in use in killing 1950s and the closest AM stereo stations in Canada about 100 miles away. Drumheller is in a deep valley and to get better reception on my receiver I had to try other whisker crystal set I decided to build a bigger antenna than I had over 1000 feet of No. 20 shot wire left on an oil seismic exploration crew and decided to use it to see if it was any good giving 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 wing jugs for insulators. My hobby space shared the base with the coal furnace. I installed the antenna using a floor joist and brought a ground wire in from my rowan tree. This antenna worked well but the weight of the wind was not to be underestimated as I started listening to modulated CW aircraft beacons. As summer storms approached I heard weird, strange whistling sounds and assumed that these sounds had something to do with my antenna. Many times the noises were so loud that they and the static crashes were hard to tell from one another. One afternoon my mother went into the 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 spark. I now realize that the dark basements 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 years later when my dad bought the home the sparks I had to take the antenna down. That led me to make a redesign of the antenna. I worked well with my 25 foot stub antenna. The article has redirected my interest and I think I will build several VLF equipment and listen but with a shorter line and not to a nice hill and a dark basement.

Kamil Kolesnik
WDSFR Tusla, Oklahoma, USA.

Your thoughts

I thought I would e-mail you after reading your reading your "readers' reviews" 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 have 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 I have 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 Electronic component. They are full of original articles and ideas and innovative projects (I'm mainly interested in audio and antenna circuits). Considering the August issue, I was disappointed that the name of another authors was omitted that that second name 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 to run a series on the design of power amplifiers in the then called EW/WW.

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

Sebastian Veyrin-Forex
France

Do any readers know the answer? Ed.

I've noticed in the last couple of months that something like 50% of author's names have disappeared from their Electronics World articles - it's quite a number. Does anyone have an 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

LETTERS

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 of those of my cat White Noise, who is wireless. Electronics World for around 60 of them. The mattresses take sets of of 50% that year. I am not sure what happens if the restringing strings also break. I found that the strings remain too much and the connection string breaks, I will shoot through the ceiling or be smothered in a collapsed mattress and I have to think about what would happen if the restringing strings also break. Alternatively would Hot October tell me the answer of his spring conundrum? I think the springs P & O are originally in series but the spring X is used in parallel. The weight X would be not easy. Well, it's easy to depend on several variables so back to the mattress. N. D.

Stripe-on-Trek, U.K.

COMPUTER NEWS

"Computer articles, small networks, software reviews, enabling technologies, digital imaging, video and audio compression, Bluetooth, Lams, etc, are not 'electronics'. They are part of a software, computer systems, information, and communications departments and programming companies. I'd also include MP3, multimedia, Internet, connectivity, multi-media, broadband, switching power supplies, digital buses, ASCII, PLAX, Digital and terrestrial TV, 'personally' interviews, any marketing department releases and, unfortunately, 'Tackling interference problems on 33.024kHz' and 'Spectrum pricing's uncertain future'.

I want to see stuff from the likes of Ian Hickman, Cyril Bateham Doug Self etc. I want to be amazed to what Kamil Krau can do with a single topic of 2002 and I want to see lots and lots of circuit ideas and readers letters. I'd like to see some general technical articles - not the masters of the art. I'd like to read the discussion of the technical details of classic top and rather limited. Articles on oddball aspects of some unusual circuits instead of a systematic review of the interesting historical aspects of our industry. More of the weird science and very simple design philosophy. Some ideas on 'near' methods of getting a particular...
LETTERS

LETTERS

October 2002 ELECTRONICS WORLD

reson and some ease studies of equipments.
I want to be educated and informed in all electronics fields and I don’t feel I’m not supported by monotonous marketing gibberish.
If you move in the direction you have indicated then yes! the advertisement reverse will return, yes! the marketing future is to be more secure. It will never ever gain the respect of Wireless World as was.
It will be different 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 gossipy, trade, advertising mag. An accountant’s return receipt.

Electronics people like me will not be paying cash for it, nor will any electronics authors be writing material for it.
The maso the electronics publishing world is falling apart in the U.K. and has been for many years now, is not the one (especially young) any is 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 crucial effort involved in web site design, or the mở market is already provided on the vastly greater reward? It’s a cultural problem with no particular end in sight, just yet another endless question of wannabe’s for the pop idol series from Electronics World’s POU and in line with no doubt, its accountant’s driving for financial return. I reckon it should be aiming itself precisely at these readers who have stuck with it for god knows however many years.

Circuit idea re-visited

Fernando Garcia’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 make a ripple regulator. I think that I would be worth repeating it.

Jean-Marc Brassart
Saint-Laurent-du-Var, France

LETTERS

October 2002 ELECTRONICS WORLD

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 wood. Remove the nicotine and you will not be selling the product.
The capture market of existing and incoming electronics enthusiasts will still be reading a newsletter of some valid content.

Yes! It will. What you want electronics design features. When I first started reading the magazine in the new sagnet, they will tell you that something in particular caught their attention or snitched your work.

What happens is that catering for a common core of readers trims your editorial to a format of 2500 to 5000 word single copy.

You look back in the archives to the heyday, you will see that the magazine has become progressively more focused on a much smaller and many thousands of components. This is the idea I would like is a simple design for a good RF spectrometer analysis. There have been ones with two but they were 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 than a few months and that don’t cost the earth. Well some food for thought.

If you write this big thunder storm is nearly overhead so I will have to terminate your untiring efforts that fateful stroke of lightning comes over and kills this machine and me with it. I’ll sign now.

By email.

I would most strongly advise going down the path of all things computer ceremmented. This would lead to the loss of many years of skill, myself being one that. There are plenty of other publications dealing with all combinations of hardware or software: Elektor 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. Oh, I don’t have special demand or some particular reason why combinations of related circuits should be included it to the readership. They will vote with their wallets and good

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

Competion has not increased, since the number of electronics titles was then just as plentiful as today. It seems that successive publishers have sought to tailor the magazine to a core readership, progressively

losing new-stan-cards. If you ask subscribers, they will tell you that the want electronic design features. When I first started reading the magazine in the new sagnet, they will tell you that something in particular caught their attention or snitched your work.

It was never much good at this highbrow stuff.

I have always been a very practical person, developing my own circuits, in thirty years I have never built any magazine based design. The thing is they never cover my requirements. I repair electronic equipment for a living. I have in the present market and many thousands of components. This is the idea I would like a simple design for a good RF spectrometer analysis. There have been ones with two but they were 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 than a few months and that don’t cost the earth. Well some food for thought.

If you write this big thunder storm is nearly overhead so I will have to terminate your untiring efforts that fateful stroke of lightning comes over and kills this machine and me with it. I’ll sign now.

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 of the customers were interested in new construction activities nowadays, so his main source of income was PC odds and ends, software and lamp.

I found a wealth of inspiration reading electronics and its successor’s, and competitors like ETI and Elektor. My first issue of EW is from 1971, and I still keep it. I have used Impression on 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 an Audio Precision set-up is still at my disposal.

In a correspondence a while back I asked about the availability of new and practical articles about the new inexpensive measurement software, 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 construction ingenuity of a modern day Lincoln-Heady. I will be using PC measurement and simulation, and builds a low cost high class measurement system to prove his point. 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 analysers, again with inexpensive PC software and hardware.

I would suggest very much like to see a practical article about low cost inter-modulation distortion measurement using PC hardware for analysis of audio equipment. So much has been written on THD measurement, but so little about of IMD, IM, etc. Could you ask Mr. Black, please?

And Mr. Black and Mr. Bateman could perhaps work together, making a synergy of their work, and perhaps a 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 sent files to present measurement results as the infinitesimal 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 you may well try over their shoulder, learn from their wisdom and duplicate the result.

So now I only ask you a good series of educational articles on the ins and outs of PC simulation, by someone who will cover the subject somewhat 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 programs.

I am aware that a great number of simulation packages at widely varying prices exist, so for the proposed series, a shareware or free software 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 your special magazines, I would very much like to see a way of downloading these layouts, for example the back issues of a 300kb windows bitmap file, or other generic graphic format that will allow the necessary detail to be printed. Maybe a modest fee per download could be set as a compensation for the initial cost. As an added value it will also serve as a popularity indicator for the magazine.

For a quick prototype, following the DIY methods of Mr. Bateman and others is too difficult.

Michael Edinger, Denmark

A warm welcome to the “Electronics World” editorial position! Your name and face will be the front page of this 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 many years and I would like to mention, 1, and by chance I recently stumbled on my copy of Wireless World: The 25th Silver Jubilee (June 1977). The first thing that was obvious was that the magazine was marked by a special front cover for the 25th Jubilee together with a short column looking back the state of affairs then 25 years ago in 1952. Very fascinating stuff!
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 I might be worth commenting an authoritative article is the controversy now being aired in RSGB's RadioCom (May 2002 p28 and subsequent issues) about whether the Crowood Field-Attena does anything more than any other bit of metal put up in the sky.

Authoritative but also comprehensible to self-taught dummies like me, please. The late, great Scroggie could have done it. I wonder, however, if Scroggie, perhaps, or Bateman, can 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 stems to the second paragraph. The letter: "Exposure" on p17 refers to "brackets on which a polycarbonate cover simply rests on." Perhaps this error was in the original email, but it should not have been published. And your editorial, your: not, which I wonder if there should be either more careful scrutiny of Circuit Ideas or a disclaimer of the "Unofficial, unofficial, 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 underspecified, if I may use 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?

Spelling or Grammar?

The 'is' or 'its' in "Eire" is probably "its" in your learned journal. How do you spell the word? The "Unofficial, unofficial, 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 underspecified, if I may use 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?

Mosfet Compensation

In his letter in the April 2002 issue, Mr. Kesler 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. This amplifier is definitely unsatisfactory.

Regarding the second design, we would like to point out that the compensation capacitors on both halves of the second long-tailed pair are rated at different values.

Presumably, it's an attempt to equalise the currents through 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 8.)

For the first design, there are two possible solutions.---first, make the Miller compensation capacitors on both halves of the second long-tailed pair rated at different values.---second, make the Miller compensation capacitors on both halves of the second long-tailed pair rated at different values.---third, make the Miller compensation capacitors on both halves of the second long-tailed pair rated at different values.---fourth, make the Miller compensation capacitors on both halves of the second long-tailed pair rated at different values.

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In my letter of January 2002, I disagreed with this kind of practice. Dr. White replied, but missed my point* and also apparently Mr. Kesler, as I didn't see an even better current source, where essentially a short ought to be. So I take this opportunity to clarify my objections. My concern was not how the current source was implemented, but why it was put there anyway and, by robbing the second stage from its ability to sink and source quite large amounts of current (e.g., approximately 1W), it may impair the stability. To improve the phase margins, C6L and C7L, the following steps have been taken.

The internal loop is a parallel combination of 1200k and 12000pF, which allows the current source to be added without significantly affecting the stability. The parallel combination of 1200k and 12000pF, which allows the current source to be added without significantly affecting the stability. The parallel combination of 1200k and 12000pF, which allows the current source to be added without significantly affecting the stability. The parallel combination of 1200k and 12000pF, which allows the current source to be added without significantly affecting the stability.

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Experimenters 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 bistable. 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 bistable. Output from the bistable forms a clock to two bistable devices. Output Q2 of the first bistable device clocks the second. Output Q3 of 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 is released to take 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 every 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, bistable clocking timer, bottom left, and the units counter/display, bottom right.

Fig. 2. Tens and hundreds display section of the pendulum timer.

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 bistable-configured 555.

To illustrate, let 40cm=0.4m and the time period of the bistable device is 0.01s. The display count is 127 so \( t_p \) is the period of the pendulum, which is 127x0.01s, i.e. 1.27s.

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

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

Switches X, Y and Z are.

initialisation resets. Normally, the bistable 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

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Fact: most circuit ideas sent to Electronics World get published

The best circuit ideas are those that save time or money, or stimulate the thought process. This includes the odd solution looking for a problem – provided it has a degree of ingenuity. Your submissions are judged mainly on their originality and usefulness. Interesting modifications to existing circuits are strong contenders too – provided that you clearly acknowledge the circuit you have modified. Never send us anything that you believe has been published before though. Don't forget to say why you think your idea is worthy.

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

Send your ideas to: Jackie Lowte, Highbury Business Communications, Anne Boleyn House, 9-13 Ewell Road, Cheam, Surrey SM3 8BZ.
Speaking clock with an educational display

This circuit 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 that 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 half and full 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 $IC_1$ contains frequency dividers so that exact Hz signal is available from pin 14. Higher frequencies can be taken from other pins.

One second cycles are taken to a decade counter, $IC_9$, the status of which is displayed in binary using LEDs. Counter overflow triggers count to six counter, $IC_9$, whose count is displayed in binary as well. Thus the seconds are indicated in BCD with two rows of LEDs.

Minutes, handled by $IC_9$, and tens of minutes, $IC_9$, are counted in the same way, but their statuses are taken via decoders $IC_4$ and $IC_9$ to seven-segment displays.

Hours are counted with a count-to-nine counter, which comprises four-bit binary counter $IC_9$. This chip is reset back to zero with a positive pulse to pins $R_1$ and $R_2$, 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 $IC_9$, 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 $IC_4$ is needed to display hours from 10 and 11.

The binary value feeding hour counter $IC_9$ is also taken to address lines $A_9$, of the voice chip, $IC_3$.

Address line $A_8$ is fed with a signal indicating full hour (0) or half hour (1). The lowest address lines, $A_{13}$, 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 $IC_3$ (pin 8) goes to ground. This happens when the output from the tens of minutes decoder, $IC_9$, achieves the value "00" or "30". When that happens, loudspeaker $L$ outputs the message from the memory slot pointed to by address bits $A_{14}$.

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 used. Other memory slots thus have 2 seconds of time, but the last one can be used up to (32-24)=8/32=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 $S_1$ ($IC_4$, pin 10) to the desired time, 6.30 for example, and stopping there by taking $S_2$ 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 $S_2$, and speak the desired message, e.g. "it is half past six." After recording $S_2$ is immediately released and thus the end-mark is generated. You can

---

**Parts list**

- Resistors (1/4W)
  - $R_1, R_9$: 0.5kΩ
  - $R_{10}$: 3.3kΩ
  - $R_{11}$, $R_{14}$, $R_{15}$: 10kΩ
  - $R_{16}$, $R_{17}$: 33kΩ
  - $R_{18}, R_{22}$: 470kΩ
  - $R_{23}$: 2.2kΩ
  - $R_{24}$: 4.7MΩ

- Capacitors (16V)
  - $C_1, C_4, C_6$: 100nF
  - $C_7$: 22pF
  - $C_8$: 22μF
  - $C_9$: 0.22μF
  - $C_{10}$: 1μF
  - $C_{11}$: 2.2μF

Integrated circuits

- $IC_1$: 4521
- $IC_2$: 74L150
- $IC_5$: 74L93
- $IC_6$: 74L93
- $IC_8$: 7447
- $IC_9$: 7445
- $IC_{11}$: 74L511
- $IC_{12}$: 74L590
- $IC_{13}$: 74LS260
- $IC_{14}$: 7805

Miscellaneous:

- 20 red LEDs for seconds and hours
- 12 small green LEDs for hour marks
- 27 segments for minutes (common anode)
- $D_{1,3}$: Small-signal diodes, e.g. 1N4001
- $X$: 4.194kHz crystal
- $S_1$: Push-button switch
- $S_2$: Switch with middle neutral position
- $M$: Electret microphone
- $L$: Loudspeaker, >150Ω

---

**Diagram**

The speaking clock's face. Hours are indicated by the red LEDs while the seven-segment display shows minutes. Seconds are indicated in BCD using further red LEDs.
CIRCUIT

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 doorknob is required. Installing is thus faster 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, IC3, which converts it to 4-bit binary format.

Received digits are stored as four, 4-bit words in the 16-bit register formed by IC2. The digits are converted to decimal using BCD-to-decimal-decoders IC4A. When a new digit is keyed, the previous ones are shifted forward. In the diagram, the last entered digit is in the left front panel of the box is darkened Perspex, 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 call 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 6cm by 5cm.

Alistair Bird

Edinburgh

£50 winner

If four digits in sequence match with the code set by the switches, output from the AND gate IC5 goes high and triggers the monostable circuit, IC6. Output from IC6 goes high for a moment, adjustable via R5B, and activates the lock relay via T1.

Four, nine-way DIL switches set the code.

With the settings as shown, the relay is powered with digit combination 7398. Digit 0 is not used because the DTMF code for zero is not the same as the BCD code for zero.

Sensitivity of the microphone amplifier can be adjusted via R3. Maximum operating distance is about 20cm. If there's a lot of ambient noise, it is best to set the phone's speaker sound level to maximum.

Heikki Kalliola

Helsinki, Finland

Heikki Kalliola

Helsinki, Finland
**0.5mV to 4.20mA converter based on chopper stabilisation**

Here is a circuit that has industrial use. 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.

![Chopper amplifier section of the 0.5mV to 4.20mA converter.](image)

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 simple:

\[ V_{in} = \frac{R_2}{R_1} \times V_{out} \]

Here, \( V_{in} \) is expressed in millivolts (0-5V). To make this work equation, you need a stable voltage gain of 800, or 58.1dB.

My converter owes its accuracy and 140dB open-loop gain to the classical chopper amplifier. This amplifier requires IC1 and IC2, with IC3, producing about 60000 of gain and integrator IC4, providing about 80000 of gain.

Total open-loop gain amounts to 140dB. This is controlled globally by \( 1 + \frac{R_2}{R_1} \). The total gain available is the product of that produced by IC1 and IC2.

Since the open loop gain is so high, it is possible to obtain 60GB amplification while still leaving 80dB spare for the closed loop. This results in incredible amplification accuracy. As shown, the circuit is set to 60GB 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 correctly calibrated, a quick linearity test can be carried out to adjust the input voltage test source to 2.5mV. The oscillator should yield exactly 12mA output.

Oscillator IC5 operates at 500Hz. It drives the two FET switches, Tr1 and Tr2, which commutate synchronously. Since IC5's signal path is isolated by \( C_2 \) and \( C_3 \), ambient temperature drifts have negligible effect.

While most transistors are very slow - they can take minutes to respond - the converter has an adequate bandwidth of about 20kHz. This can be altered by changing the R1/R2 gain.

The chopper amplifier 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 above.

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).

**Circuit CAD on a shoestring**

Need a means of drawing circuits in a presentable fashion and in such a way they could be easily modified using existing software? I decided, for 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 quick acceptable results - importantly, at no extra cost.

First, open the symbol library in one PC Paint window and 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 can be performed 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 size for saving drawings is attained by reducing page size to just fit the drawing (Image, Attributes menu) and saving the work as a monochrome bit map. 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 j.lowe@thighsbyhix.com using the subject heading CAD file.
THE IEC 320 CONNECTION

NEW PRODUCTS

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Wire harness saves 45% PCB space

The 1.25mm (0.049") pitch Mini MIll wire harnessing connector system from Molex is designed to save about 45% of PCB area compared to similar 2.00mm (0.079") pitch versions for applications such as printers, home appliances and automotive electronics. 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 single-row IDT receptacle that provides mass termination of discrete widths. The receptacle has guide slots to facilitate wire placement.

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typical for

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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.

Mobile processor with camera

Hitchi's second version SH-Mobile application processor, the SH7294 incorporates a SH3-DSP CPU core with an operating frequency of 200MHz, 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 H93D170BP Multi Chip Module (MCM), which incorporates 1MB byte 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 mm pitch, CSP-225 package. Hitchi's second version SH-Mobile application processor, the SH7294 incorporates a SH3-DSP CPU core with an operating frequency of 200MHz, 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.

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Power resistor rated to 1500W

Designed for applications where traditional heatinking is not practical, the BPR series high-power resistors from Tyco
One transistor SRAM design. The products are organised in 2-bit, 16, 32, 64, or 128-bit word read-write transactions. The products are available with 25V or 3.3V power supply options and 100-pin TQFP and 119-pin PBGA packaging options. It is pin-compatible with existing 185MHz no bus latency or ZBT SRAM products.

NEWPRODUCTS

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## NEWPRODUCTS

### 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 voltage 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 the first time this secondary side regulator with an available gate drive voltage can actually be below the output voltage, which is a sought feature 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: +6943 8141 61020

www.fairchildsemi.com

### Mezzanine connector supports 10Gbps/ data

Providing differential and single-ended ground-signal-means communication between parallel mounted PCBs, the GIG-Array mezzanine connector handles data rates up to 10Gbps. This BGA receptacle and plug system accommodates up to 392 signals per connector. High-speed performance is supported by the connector’s 1000 differential pair matched impedance design. The result is a maximum performance of less than 2 percent. This results in extremely high signal integrity, maintaining the same signal frequency range, said the supplier FCI. Multiple stack heights range from 15mm to 35mm and connector sizes support between 104 and 392 signals.

**FCI**

Tel: +6933 3849 2082

www.fci.com

### 2.5V solid-state relay is 5mm wide

Fider’s first solid-state relay is a version of the company’s 34-series electromagnetic PCB mounting part. Designed the 34.8I, 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 suffixed 7048 - can switch up to 100mA at 24V DC. Each can be specified for 24V or 30V DC control input. Featuring silent operation, the 34-series solid-state relay has a footprint of 28mm by 5mm and measures 15mm high. It mounts on the PCB via its
NEWPRODUCTS
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solder pins. Dielectric strength between the input and output of this relay is 2.5kV.
Finder
Tel: +49 (0)1785 618100
www.findemet.com

2.4GHz spread-spectrum technology
AeroComm has published brochures which are intended to expose a number of what the 2.4GHz spread-spectrum wireless systems 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 IEC 11 standard which the company claims is somewhat erroneously known as the industy standard. Another looks at single frequency radios. Finally, Bluetooth comes in for a pasting.
AeroComm
Tel: +49 (0)1908 206342
www.aerocomm.com

Channel device for DDS systems
TranSwitch has an IC plus software for next generation channelised DDS/DS1/DS0 communications network applications targeting wireless access, multi-service access platforms, time division multiplexing (TDM) over packet, and echo cancellation. Called TBEPro, it is a 1 to 8 processor-based device with embedded DD-AMPS firmware and host API supporting the requirements of next-generation channelised DDS access systems. Supporting either one DDS, 28 DS1, or 21 E1 line interfaces, the device can be configured for different operating modes. It integrates an M130G747 multiplexer including a DS3 frame with full C-C functionalities to support clear-channel DS3, a 28-channel E1 framer, and a 28-channel DS1/E1 cross-connect.
TranSwitch
Tel: +49 (0)202 1660 7580
www.transwitch.com

CAN controller can be pre-qualified
Atmel has announced pre-qualification of its CAN microcontrollers for automotive temperature ranges. The devices implement self-programming code flash memory and data EEPROM. By executing the CS1 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 at 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 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 header, or a one-piece moulded plastic panel. There are seven sizes in the family ranging from 80x54x23mm to 220x103x5mm; 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 190x162mm or 190x220mm Eurocard respectively.
Hammond Electronics
Tel: +44 (0)1366 812812
www.hammondmg.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 Rise 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 QFT20 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 percent reduction per sensing channel over its previous product family. The device uses signal processing techniques to tackle "snack sensor" conditions and drift. The chip's EEPROM and communications port let the user program the device from a PC using Quantum-supplied software and adapter. All operating parameters can be user-loaded into the part's internal EEPROM to configure sensitivity, drift compensation rate, response time, and output polarity. The part also features user-configurable automatic recalibration and output toggle mode. Power consumption and speed can be tailored depending on the application; drain can be 60mA, allowing battery operation. The chip's 8-pin DIP and SOIC packages are available; the temperature rating is –40°C to +85°C.
Quantum
www.qprox.com

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Electronics World October 2002

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

As I had described how, by using the back cover 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 inductance, this inductance is not constant but varies with the voice coil's position in the frequency band. As an influence on the high frequency response of a driver because it forms a series resonant circuit with the reactive component of 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 voice coil in the positive feedback circuit. This appears as a negative inductance at the amplifier's output, thus compensating 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 2kHz -3kHz. Of course, just as much attention must be paid to the entire frequency range as well as 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 MDT79. This is a high quality 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 8mOhm impedance 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 100dB/W/m was designated for. If my neighbours are to be believed this is more than enough output. With a 86dB/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 output power of 1000 watts. This works out 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 liters.

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 evaluate phase shifts in odd order crossovers and is popular in the US where it is known as the 'D' Appollonio 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 millimeters from the cone. No signal gaging is used. The response clearly shows the bass resonant peak and roll off. Measuring the impedance curve showed that the system was operating as a hi-pass 2nd order filter with a turnover 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 broadening 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 quadruple op-amps. Although this made the pilot unit of my design difficult 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 works best. Only first order crossovers are free from this defect. Unfortunately the range of the drivers needs to be extremely wide for such a crossover to be viable.

A better problem that can be 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 unequalled system rises at 12dB/octave below 2KHz, levels out at 20kHz at 0.5kHz below 100Hz. It remained constant to 1kHz above 1kHz at 1kHz at 2kHz. The response of the 3-way system is shown in Figure 3. This is quite good but there is no doubt that it could be improved with the application of some form of Q control, as described earlier. I decided that the response could be rendered sensibly flat by a simple shelving filter. Using this approach the response within ±4dB between 100Hz and 1kHz was obtained. Figure 3 shows the overall response obtained by the equalised system.

The response of the equalised system is shown in Figure 4. This is quite good but there is no doubt that it could be improved with the application of some form of Q control, as described earlier. I decided that the response could be rendered sensibly flat by a simple shelving filter. Using this approach the response within ±4dB between 100Hz and 1kHz was obtained. Figure 3 shows the overall response obtained by the equalised system.

More importantly was that the sound was now right. Although the drivers are well known I didn’t think that there was a crossover unit. Some might question whether the tweeter is 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 0.1uf capacitor adequately protects this driver from low frequencies. In fact the acoustic response of the driver/cap combination is ±4dB down at 100kHz. I didn’t bother to include the tweeter in the motivational feedback loop though. There are two reasons for this. Firstly, 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 the output of the woofers leading to unpredictable results.

However, the use of a full range speaker system without crossover is not unusual. I would like to mention one of my author's first Wireless World article, 'Low Cost High Quality Loudspeaker' as an expression for this system. In the above mentioned article the author described using equalisation to a small full range speaker to obtain a 1kHz to 1kHz flat response. The equaliser consists of a pair of a 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 a non-inverting input of the 10-40kHz range. The next stage of the bass equalisation consists of the boost feedback amplifier built around A3. This applies gentle boost bass boost between 500-2000Hz. The filter consists of C4,R1 and R2. The gain of the circuits, 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’s is deliberately damped by the hi-pass filter comprising C5,R6 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...
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 100,000pF types and are somewhat smaller. Stabilised power supplies are used for the equaliser circuits. Voltage regulator 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 P1 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 brass 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.

![Diagram of circuit](image)

**Component list**

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**Figure 4c:** Cross-over schematic

**Figure 5:** Equaliser overall response

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 cut to it to size. There's nothing worse than trying to make enclosures with wrongly sized pieces! The main requirement of the enclosures is that they are airtight when assembled. Epoxy rapid is an excellent glue for this purpose. However, it pays to run some interior Polytills down the seams to be sure. You will notice that the enclosures contain nothing more complicated than this. 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 internal 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 jig was made 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 leads is more than adequate, especially as a length of 50cm can be clamped. A knife will be ample.

Now the final 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 Q6 in series whilst slowly adjusting PR1 clockwise. Set this voltage between 10 - 20mV using a multimeter. Apply a signal to the input and advance VR1. Undoubtedly sound emanates 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 into place with masking tape. Drill 3mm holes around the periphery of the panel into the assembled cabinet. Counterbore 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 gives an excellent transient response. Bass is solid and extended and the stereo imaging is three dimensional with good recordings.
透明V-I保护在音频功率放大器

“厌恶是由一些设计者对V-I限制在音频功率放大器是完全的错觉。”Michael Kiwanuka在他的第二篇文章中讨论了在音频功率放大器中实现无妥协的输出保护技术。

在上月的讨论中，单极型、单极型无极型反折电阻限制，这个新节段覆盖了单极型的替代方案。

引入一个电阻器，R_d，在系列中与二极管在图27中列出的电压降的总组合，该组合是线性大于二极管的传导阈值。在图26中，可以使用R_d来表示段B-D在保护点的阈值。使用该阈值和R_d之间的关系，可以更好地理解阈值点的偏移。对后文中的这些二极管的R_d和I_d描述在第1部分中已经概述了。

(b) As is the case with single-slope, linear foldback limiting, segment B-D must intersect the safety operating area's V_{op} 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_{op}=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_{d1} established as 8k2, are shown in Fig. 30, using any convenient set of points along A-B-D.

With reference to Fig. 28, and selecting R_{d1}=8k2, I_{d1}=1mA, and:

\[ R_{d1} = \frac{0.6}{0.88} \times 8k2 \]  \hspace{1cm} (10)

From equation 10:

\[ (40 - 4.6) - 1mA = 0.6 \times 8k2 \]  \hspace{1cm} (12)

From Fig. 29, and invoking equation 11:

\[ 0.6 \times 3.08R_1 \times 0.6/0.88 \]  \hspace{1cm} (13)

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

\[ R_1 = 704R_7 \]

\[ R_{d1} = 356/9 \]

And:

\[ R_{d2} = (0.6/0.88)\times R_{d1} = 243R3 \]

With reference to Fig. 30:

\[ I_1 = 0.6/0.88 \times 8k2 = 2.47mA \]

\[ V_i = (I_1R_{d1} - 39V4) = -38V52 \]

\[ V_{rs} = (V_i + 39V59) = 1V37 \]

\[ I_1 = (V_{rs}/R_1) = 1.94mA \]

But, \[ I_d = I_{d1} + I_1 \]  \hspace{1cm} (14)

Where:

\[ I_d = (40 - V_{op})/8k2 = 9.58mA \]

\[ I_d = 9.58mA \times (2.47mA + 1.94mA) = 5.17mA \]
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 $V_p = V_{sat}$, only points A and F on locus A-D-B-F are required to obtain a solution.

With reference to Fig. 33, let $V_p = 220V$, and $V_{sat} = 40V$:

$$I_A = I_F$$

Where,

$$I_A = (-39.4 + 39.78)/220R = 1.73mA$$

and

$$R_A = (40 + 39.3)/1.73mA = 46K$$

With reference to Fig. 34:

$$I_A = (40 - 39.52)(R_s / R_1) = 2.48/219R = 11.33mA$$

With $V_p = 40V$ at 11mA,

$$R_1 = V_p / I_A = (31.72 - 0.7)/(11.33mA) = 3K$$

This scheme is clearly inferior to the standard linear foldback arrangement of Fig. 1. It delivers only 1A at $V_p = 435V$, requiring a minimum of six output pairs for 402s 150mA load drive from a 50V supply rail.

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, $V_{sat} = V_{ref}$. This enhances the flexibility of the circuit, as the breakpoint can now be moved purely 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, $V_{ref} = -16V, 33$ and $V_{sat} = +6V, 33$. This calls for a nominal $5V, 33$ zener diode. As previously recommended, multiple low-voltage devices should be used to minimise series impedance.

With reference to Fig. 37:

$$I_A = I_F$$

Where,

$$I_A = (-39.4 + 39.78)/220R = 1.73mA$$

$$R_A = (40 + 39.3)/1.73mA = 46K$$

Referring to Fig. 38:

$$I_A = (40 - 38.4)(R_s / R_1) = 1.6/219R = 7.3mA$$

With $V_p = 40V$ at 7mA,

$$R_1 = V_p / I_A = (38.4 - 0.65 + 16.33)/7.3mA = 7K$$

Note that there is no change in the value of $R_1$ and $R_A$ in the circuits of Figs 5, 31, and 35, with different values of $R_2$ 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, the gradient of segment E-F, being part of C-D-E-F, is determined by resistors $R_{1,3}$ and limited by practical values of $R_2$ - an affliction absent in the circuit of Fig. 27.

Complete independence from $R_2$ 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, $R_2$, Fig. 39, for each protection transistor. The result is in fact merely a union of the linear single slope segment of Fig. 1, and the non-linear single slope circuit of Fig. 2.

The linear, single slope locus in Fig. 2 is reproduced in
management are assumed.

To this end the treble-slope design in Fig. 43 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 $R_6$ pulls the base of the protection transistor low as appropriate for $0V \leq V_m \leq 42V$, 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,

$$V_{ref} = V_{out} = \frac{|V_m|}{2} - 7V23$$

with $V_{ref}$ at 7V23 and $V_{ref}$ at −7V23.

As previously established for Fig. 27, component values without $R_6$ are calculated for segment B-D-E, (Figs. 44 and 45), and the value of $R_6$ established in situ, Fig. 46, using any convenient set of points along D-F. Resistor $R_6$ is then calculated for a nominal $V_m=0V$, at point A Fig. 47.

With reference to Fig. 44, let $R_{4}=8.5K$, and $V_{m}=0V$ when $I_2=1mA$.

$$I_2 = I_1 = I_1 + I_2$$  \hspace{1cm} (15)

And,

$$R_4 = 0.6 \frac{V_m}{R_6}$$  \hspace{1cm} (16)

From equation 15:

$$\frac{(50 + 11.5)}{8K2} = 1mA + \frac{0.6}{R_6}$$  \hspace{1cm} (17)

From Fig. 45, and invoking equation 16:

$$0.6 = \frac{0.6}{R_6} + \frac{8.2R_6}{R_6}$$  \hspace{1cm} (18)

Solving (17) and (18) simultaneously:

$$R_6 = 160K$$

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 discrete 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 $V_{ce,<}V_{ce,C}V_{ce,L}$ region. However, for purely resistive laboratory loads with which a power amplifier's published specifications are obtained, the $0V < V_{ce,<}V_{ce,L}$ 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 1Ω – without limitation, may be commercially rewarding. A suitably robust power supply and conservative thermal protection are achieved.

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**Project 54:**

**Resistor vertical 125**

Dealing with the handling of resistors, the vertical method is shown in Fig. 40 as segment B-C-D, for which equations (1) and (3) are valid. So, referring to Fig. 41, with $R_2=220K$, then $R_1=12K4K$, and $R_1=143E$. Resistor $R_1$ pulls the base of the protection transistor low as required for $0V \leq V_m \leq 42V$, giving segment A-C.

The reference voltage is equal to the output voltage when $V_{out}=42V$, thus,

$$V_{ref} = 40V - (42V + (3A5 \times 0.822)) = -2V77,$n

and $V_{ref}=2V77$.

Referring to Fig. 41:

$$I_1 = I_1 + I_2$$

$$I_2 = I_1 + I_1$$

$$I_2 = (40 - 37.96)/12K4 + (40 - 37.96)/220K \times 0.6/143E$$

$$I_2 = 5.24mA$$

With $V_{ref}=0V$,

$$R_2 = V_{ref}/I_2 = (37.96 - 0.6 + 2.77)/5.24mA$$

$$R_2 = 1K7$$

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 discrete value zener references.

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

**Figure 42:** Treble slope, dual breakpoint, non-linear foldback limiting.

**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-E 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, 
\[ I_1 = I_{in} - (I_1 + I_s) \]
Where, 
\[ I_1 = (40 - V_1)/8.27 = 10.85\text{mA} \]
\[ I_s = 10.85\text{mA} - (2.75\text{mA} + 5.79\text{mA}) = 2.31\text{mA} \]
\[ R_1 = (V_{in}/I_1) - (V_{in} - 0.6)/I_s = 1430 \]
From Fig. 47:
\[ R_f = (V_{in}/I_f) \]  
(20)

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

\[ I_s = I_{in} - I_s \]
(19)
\[ I_s = (50 - 47.96) \]
\[ = 0.6 \]
\[ = 3.67\text{mA} \]
\[ R_s = (47.96 - 7.23 - 0.6)/3.67\text{mA} = 10.89 \]
A 40A current driven to a 50V rails requires a 94.5 when \( v_{be} = 55\text{V} \), resulting in peak transistor dissipation, \( P_{D,\text{max}} = 55\text{W} \). The treble slope protection locus of Fig. 43 allows 2A at \( v_{be} = 59\text{V} \) for a single complementary transistor pair. Therefore, five complementary pairs are required to drive a notional 450A 600V loudspeaker system from 50V supply rails without intrusive limit 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 0V 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 ZP06.8RL, in series with a single ZP08.2RL, biased at a nominal quiescent current of 10mA by \( R_r \). A more elegant -- if rather tedious -- approach\(^6\) 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 coefficients), tends to counteract the increase in zener voltage with increasing temperature, (positive temperature coefficients), and conversely. Therefore \( Z_1 \) and \( Z_2 \) may each consist of a series combination of three 1N961B 10V zeners, a single ZP08.2RL 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 current fluctuation is invariably more significant than that due to change in temperature. Where con is no object, \( R_r \) may be replaced with a temperature compensated resistor \( R_{3}\), current source/sink, Fig. 49. This can be in the guise of a LED-biased transistor, \( T_{eb} \).

LED current limiting resistor \( R_r \) is split symmetrically into two components, \( R_1 \) and \( R_2 \), whose intersection\(^6\) is decoupled by capacitor \( C_{Gx} \) to the supply rail. The single-pole filter comprising \( C_{Gx} \) and \( R_2 \) across the LED's internal resistance, in series with \( R_2 \), improves the regulation of the voltage drop across the LED by diminishing power supply ripple in the current established by \( R_2 \) and \( R_3 \).

A time constant, \( R_2 C_{Gx} \), of the order of two seconds is significant. Correcting \( C_{Gx} \) directly across the LED is sub-optimal, as a comparatively larger component would then be required for the same time constant.

Resistor \( R_r \) minimises power dissipation in \( T_{eb} \), 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.

Figure: Figure 49. Treble-slope, dual breakpoint limiter of figure 42, with improved regulation of zener voltage, \( V_z \), by means of a temperature compensated current source/sink. Such regulation is further enhanced by the introduction of a measure of temperature compensation to \( Z_1 \) and \( Z_2 \).

Protecting paralleled complementary output transistors
Emitter resistor, \( R_p \), performs current-voltage conversion for the V-I limit. It also promotes thermal stability by maintaining equal current distribution in a paralleled pair output stage. For this reason some designs suggest\(^6\) 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, \( R_p \), for a single complementary transistor pair is multiplied by the number of paralleled output pairs, \( N \), with each resistor of value \( \frac{R_p}{N} \) 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 \( \frac{R_p}{N} \) be shunted by the diode in series with resistor, \( R_p \), whose value remains unchanged.

An obvious disadvantage inherent in both schemes is that the failure of a single 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 MIL3281A-NUL502A transistors. Higher supply rails are not recommended for worst-case reactive loads, as available collector current for these devices falls rapidly below 50mA with a VCC of more than 100V.

Although e-MOSFETs are at least an order of magnitude less linear than bipolar transistors[1,2,3], they provide significantly greater scope for reliable design at high device voltages, (2V<sub>DM</sub>, V<sub>DM</sub>>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-to-voltage region, I<sub>C</sub> = V<sub>CC</sub>/2RL, where it counts with respect to reactive load drive, is negligible in relation to the circuit complexity thus engendered.

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

In Michael's previous article, "qu" should have been written as "qu" in three places — 6, 8 and 18 lines from the bottom of the right-hand column of page 46. Also, the words, "decade DP and DF are omitted in subsequent figures in the interest of clarity," should have appeared at the end of the last paragraph on page 46. In Fig. 4, the voltage at the base of T<sub>p</sub> should have read 3V72, not 3V72, in Fig. 7, the voltage at the base of T<sub>p</sub> should have read 39V4, in Fig. 15, the voltages at the base of T<sub>p</sub> should have read 350V3 ↔ 350V4, and finally, in Figs 24 & 25, V<sub>SR</sub> at the end of R<sub>p</sub> should have read 20V6.

Apologies for these errors.
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