Electronics World's renowned news section starts on page 5

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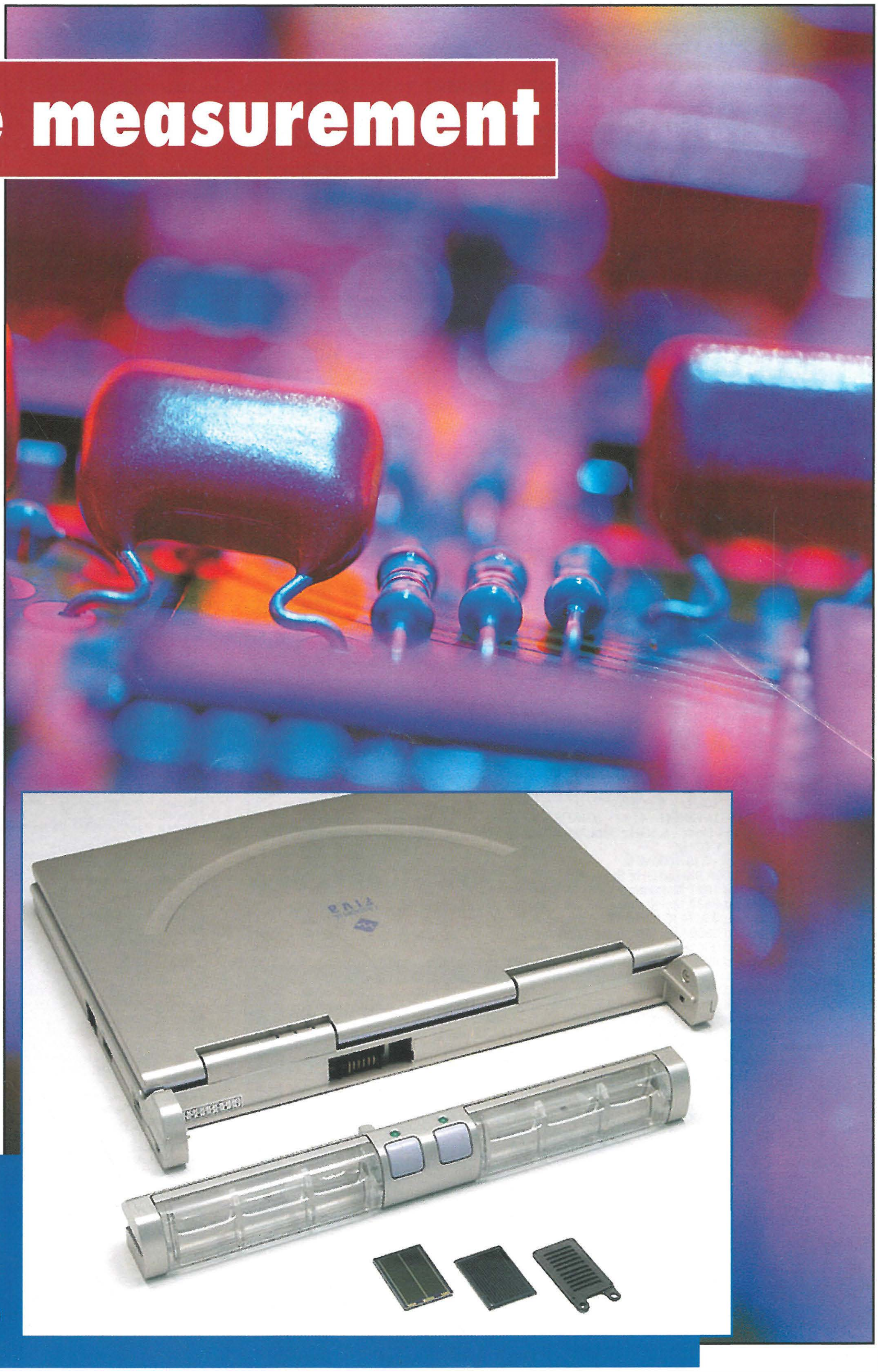

Impedance measurement

Capacitor sound part 5

RF Auto transformers

Circuit ideas:

Solid state latching relay

Electronic indicator for motorbikes

Audio activated switch

Casio fuel cell for PCs

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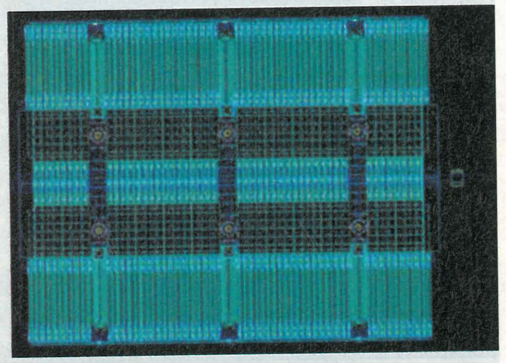

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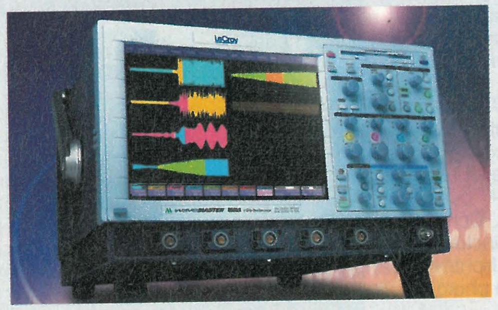

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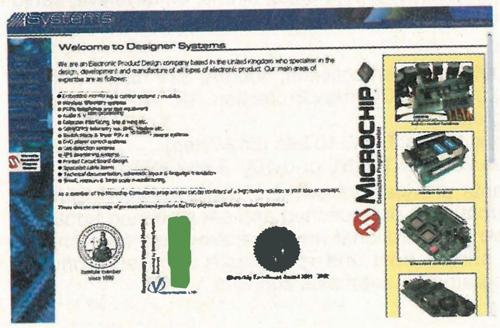

EDITOR
Phil Reed
p.reed@highburybiz.com

CONSULTANT
Ian Hickman

CONTRIBUTING EDITOR
Martin Eccles

EDITORIAL ADMINISTRATION
Jackie Lowe
020 8722 6054

EDITORIAL E-MAILS
j.lowe@highburybiz.com

GROUP SALES
Reuben Gurunlian
020 8722 6028

ADVERTISEMENT E-MAILS
r.gurunlian@highburybiz.com

EDITORIAL FAX
020 8722 6098

CLASSIFIED FAX
020 8722 6096

PUBLISHING DIRECTOR
Tony Greville

MANAGING DIRECTOR
Roy Greenslade

ISSN 0959-8332
SUBSCRIPTION QUERIES
Tel (0) 1353 654431
Fax (0) 1353 654400

A to D conversion

I've had a few letters this month about how much better analogue audio sounds compared to anything digital. Spurred on by this, I thought I'd share with you one of my own personal A to D conversions.

I recently went out (well, picked up my mouse and credit card, actually) and bought a DVB TV receiver. And the only reason I did this was because a UK chain was selling them on the internet for £60, which seemed pretty good and certainly much less than changing my otherwise perfectly good TV. I ought to add that the reason that DTV boxes are so cheap in the UK at the moment is because the commercial broadcasters who were on the platform went bust. And the silly distributors thought that the boxes were almost worthless. But the BBC are taking over the whole platform and will provide more (non-subscription) channels and are also going to up the data rate.

All this is jolly good news for me, when you consider the cost of the box. But all is not roses. On switching on the aforementioned box (and after an interminably long 'auto programme' sequence) my first taste of DVB in the home arrived. Yes, the pictures are sharper, which should come as no surprise as the box delivers RGB to my TV – not going anywhere near PAL and hence nowhere near my low bandwidth decoder (it's only posh 'comb-filter' decoders that deliver the full broadcast bandwidth). But the low data rate causes 'blocking' on fast moving objects and dissolves (mixing from one scene to another) and movement artefacts that can look like a quick succession of freeze frames. OK, three-quarters of the time things are acceptable – but the other quarter certainly is not.

As usual the great consuming public has been sold digital as better. It's true, that when CDs arrived the sound quality (to most people) was better. The media was a lot more resilient and portable and the hardware was quite cheap to produce, meaning that a low price player would sound better than its price equivalent in analogue. That was in the heady days of no data compression – just a fairly good sampling rate, 16-bit depth and good error correction. Audio does not take up much room, but video certainly does, which is why it can look bad – especially when accountants get their grubby hands on the system and try and squeeze far too much down the available pipe.

Governments also delude themselves on matters digital. The UK government keeps harping on about 'broadband Britain' but has offered hardly any incentive for broadband service suppliers, or the public to go 'digital'. The new G3 phone system will have a serious bandwidth for portable, and even home use. This could have been used for fixed services as well. But the ridiculous auction situation that most European governments put the telcos through has scuppered that idea until they get a return. And since we are talking billions of whatever currency you fancy, it's going to take some time.

The other broadband alternatives are also getting less penetration than a decent roll-out deserves. Cable is only viable in urban areas and the health of the cable companies suggests that areas with lower revenue potential will be a long time off being cabled. DSL services are great – but subscribers need to be quite close to their fibre point, meaning that again remote dwellers will not be on the superhighway for a while.

But there is an alternative. A study group is working on a variation of DVB that allows a data return path. In fact, I ran an article on this subject in my last magazine over three years ago, and that was about the last I heard of it. The idea is pretty simple – you put a small (1W) transmitter in your set top box. The output is sent up to your receive antenna and carries encoded data back to the local DVB site. From there it can be plugged into whatever transport media you like. Spare capacity on the data carousels (opportunistic) can be used as the incoming data line (or even dedicate a whole channel for the purpose). Now a system like that would not alienate people who choose to live a few miles from a town and would truly 'broadband' up any country. And cheaply too.

***Phil Reed**, Editor.*

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Casio makes fuel cell for PCs

Fuel cells for laptop PCs and other handheld consumer devices are being developed by Casio. The Japanese firm said its design is unique, despite being based on the commonly used direct methanol fuel cell (DMFC) format.

Casio has developed what it calls a micro-reactor, a device made from silicon to reform methanol and water and produce hydrogen. The firm claims 98 per cent efficiency for the design.

The silicon reformer was produced in-house, while the catalyst used in the process was developed at Japan's Kogakuin University.

The electricity generating section of the fuel cell recombines hydrogen with oxygen to produce energy and water.

Casio has tested its design in its Cassiopeia FIVA laptop (pictured), which runs for 20 hours on fuel cells, four times longer than a lithium ion battery can manage.

The firm points out that making batteries consumes large amounts of power. It is generally reckoned that it takes 50 times as much energy to make a battery as ever comes out of it.

Production of fuel cells is expected to start at Casio by 2004, ahead of the industry's plans for the devices.

Meanwhile, a research organisation has been set up by the European Union in order to investigate hydrogen as a power source for vehicles and fuel cells.

"Hydrogen marks a revolution in how energy can be produced and stored," said the EU research commissioner Philippe Busquin. The latest work on hydrogen in the EU is scattered, resources are scattered widely, and costs are high, he said.

Various research centres,

component and fuel cell system makers, utilities and energy companies and transport bodies will be represented in the group.

Stamping out optoelectronics

A team of UK scientists has created a technique for embossing photonic structures onto light emitting polymer substrates.

Researchers at the University of St Andrews collaborated with colleagues at Exeter University to produce structures such as Bragg gratings. The work could dramatically cut the cost of LEDs and optoelectronic components.

"Our group is very interested in using polymers," said Justin Lawrence from St Andrews and the lead author of a paper on the technique. "One of the advantages of polymers is they're very easy to process."

However, to make useful photonic microstructures such as gratings and LEDs, the polymer must be processed using complex, expensive processes, such as electron-beam, photolithography or chemical etching. "Hot embossing is very easy," said Lawrence.

In order to make structures, a master is patterned into silica using conventional methods. The polymer substrate is heated to 20°C above its glass transition temperature of around 200°C, at which point it starts to flow.

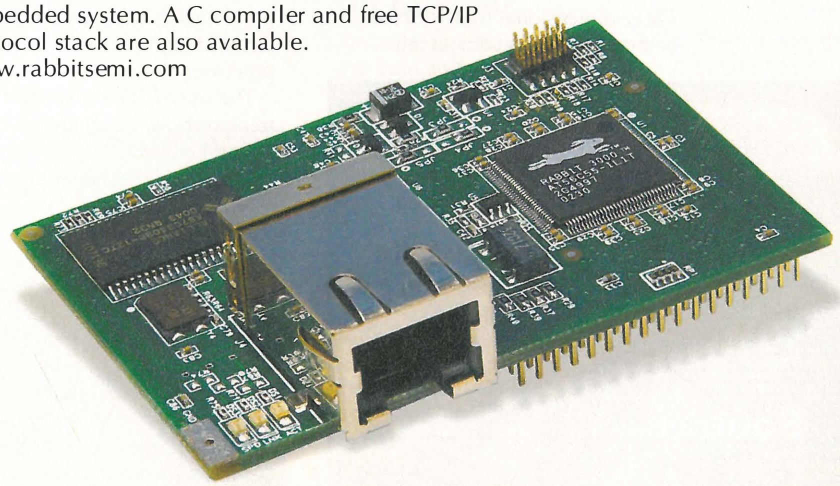
The master is pressed into the polymer and, once it has taken the shape of the mould, the polymer is cooled. A non-stick chemical between the master and polymer stops them bonding together.

The team has embossed a cross grating with a period of 400nm and depth of 20nm which can couple light into and out of the material through Bragg scattering. Moreover, the team used a conjugated polymer known as PPV, which has the desirable attribute of being a light emitting material.

Using PPV, St Andrews' researchers have constructed LEDs using conventional etching techniques. Lawrence hopes to use the embossing technique to form more complex structures in the near future. "There will be some problems, but it's not too far away from happening," he said.

Lasers and LEDs made using Bragg reflectors are very well understood and should be possible to manufacture.

Rabbit Semiconductor has created this 10/100 Ethernet board around its own processor design. Squeezed into the 69x47mm board are six serial ports that can alternatively be set as up to 52 digital I/O lines. The on-board processor can also be used as the main controller in an embedded system. A C compiler and free TCP/IP protocol stack are also available.
www.rabbitsemi.com



Diamonds are a chip's best friend

Diamond has moved a step closer to being used as a substrate for semiconductor development, following work by Swedish and British researchers.

Jan Isberg from ABB's nanotechnology and materials group in Sweden claims to have grown single crystal diamond, a major stumbling block to commercial production. Working with experts from De Beers Industrial Diamonds in Ascot, the team avoided the polycrystalline forms that usually result from synthesising diamond.

Moreover, Isberg's team are also able to dope the crystals to create a p-type semiconductor and then fabricate p-i junction diodes on the substrate.

Chemical vapour deposition is used to grow pure layers of diamond on a synthetic diamond substrate. Thicknesses up to 700μm can be grown, and then removed from their substrate using a laser.

By doping layers with boron, and then adding pure diamond layers, the team produced p-i diodes with a reverse breakdown exceeding 2.5kV.

Diamond has excellent physical characteristics and shows tremendous promise as a semiconductor, once a reliable synthesis can be achieved.

Isberg's team measured a very high electron mobility of 4,500cm^2/Vs, at least three times that of silicon, while holes at 3,800cm^2/Vs have very nearly the same mobility as electrons.

Only indium phosphide (InP) comes close in terms of electron mobility, but its hole mobility is very poor in comparison (5,400 and 200 cm^2/Vs respectively).

A maximum electric field strength of 10^7V/cm is two orders of magnitude better than silicon or gallium arsenide (GaAs), and better than gallium nitride (GaN) or even silicon carbide (SiC). Diamond's indirect bandgap is 5.5eV.

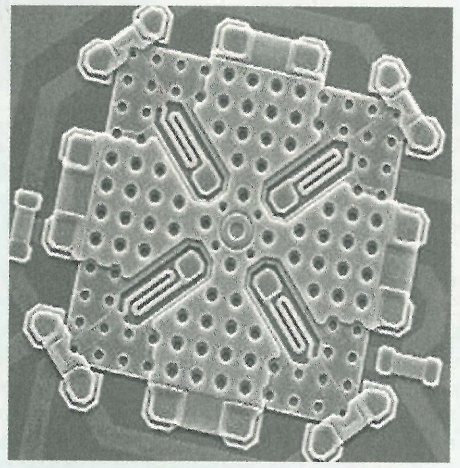
Motorola has used micromachining techniques to create a family of accelerometers with ranges from 1.5 to 8g.

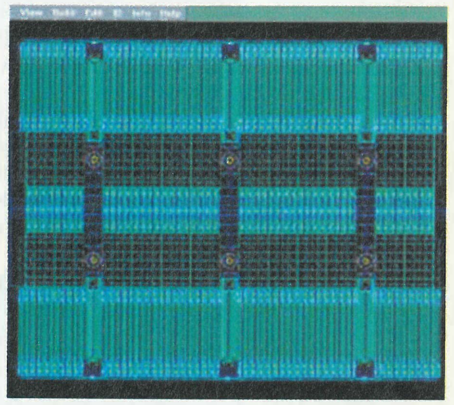
The devices are aimed at sensing shock, vibration, tilt, movement or acceleration. The sensors include signal conditioning, temperature compensation and zero-g offset.

All five devices in the family are single axis sensors in 16-pin small outline packages. Z-axis sensors come on 1.5, 2.5, 5 and 8g forms, while there is also a 1.5g x-axis device.

Typical applications include washing machines, video game pads, seismic detectors, security systems and vehicle roll-over detection.

Not to be outdone, Analog Devices has developed a gyroscope that it claims is the first commercial device to integrate both an angular rate sensor and signal processing electronics.





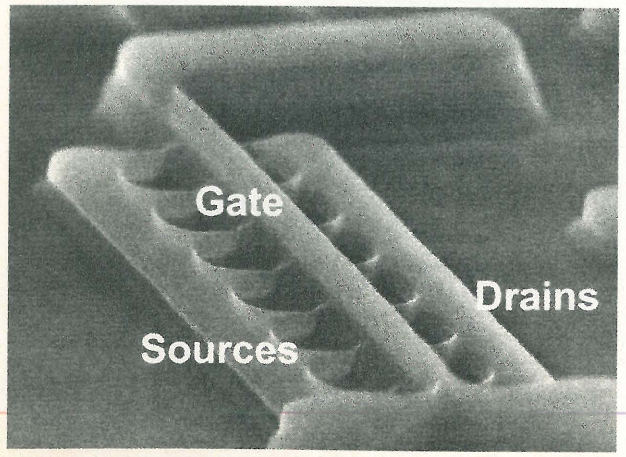
Above X-lateral g-cell
Left Z Axis g-cell

The ADXRS is mounted in a 7x7mm ball grid array package, and draws 5mA at 5V. The gyro is aimed at applications such as car airbags during rollover, GPS navigation systems, and stabilising moving platforms such as aeroplanes, robots, antennas and industrial equipment.

Two devices are available, capable of measuring angular rates of 300 or 150 degrees/s.

Intel goes 3D to cut leaks

Three dimensional transistors are being designed to combat the problems of leakage current and the diminishing returns as manufacturing processes shrink.



The use of 3D designs for transistors, as compared to today's planar layouts, can help reduce leakage and give better power efficiency.

"Our research shows that below 30 nanometres, the basic physics of the flat, single-gate planar transistor leaks too much power to meet our future performance goals," said Dr Gerald Marcyk, director of Intel's components research lab.

Marcyk's team recently unveiled Intel's approach to the problems of scaling with its tri-gate transistor.

In this layout, the channel between the source and drain is a 3D structure, with the gate wrapping around three sides. Current flows equally in a channel occupying all three sides of the structure.

The image shows a tri-gate transistor with multiple fingers to improve current flow.

So far Intel has built devices with gate lengths measuring 60nm. Compared to a planar device with similar dimensions, the tri-gate transistor give 20 per cent more drive current.

A fully depleted silicon substrate is used to raise switching speed and help reduce leakage, while the raised structure of the whole device helps to lower resistance, Intel said.

Fizzle cuts antenna testing costs

A Merseyside invention could cut the cost of antenna testing.

The standard way to plot the response of an antenna is to put it on a rotary mounting and connect it to a receiver with an antenna some way off providing a signal. Unfortunately the test has to be performed in an open field or in an anechoic chamber otherwise reflections ruin the results. These options are inconvenient or expensive.

With the Merseyside method "you don't need an anechoic chamber, you can accurately measure the radiation pattern in an ordinary laboratory", said Dr David Parsons who has founded a company called Fizzle Technologies to exploit the invention.

Fizzle's modified test set-up involves initially replacing the antenna-under-test with an antenna with known characteristics.

It also requires an equaliser, a device which provides a different attenuation and phase-shift in the receive path for each angle the antenna is measured at, in front of the receiver.

The equaliser is then adjusted until the known antenna plot is correct.

Once the equaliser is set, the unknown antenna can be measured and results will be as though no reflection paths were present - providing the antenna-under-test "positioned within one tenth of a wavelength" of the known antenna, said Parsons.

Results so far are encouraging and the technique could be extended to improve existing test sites.

Parsons and co-founder Dr Paul Leather, both formerly of the University of Liverpool, are currently concentrating on phone-type small UHF antennas.

Fizzle is funded by a £45,000 DTI SMART award.

www.fizzletechnologies.com

Power firm has designs on web

A website devoted to power supply design has been developed by International Rectifier.

The first incarnation of the site, called myPower, is able to design multiphase DC-DC converters in the 20 to 80A range. Designs can have 1.1 to 1.85V outputs and 200kHz to 1MHz switching frequencies.

In the future the firm expects to extend myPower to work with other DC-DC converters, AC-DC power supplies, generic switch mode supplies and lighting circuits.

"Systems are getting more complex, require more power and lower voltages," said David Schroeder, design services manager at IR. "We need to provide these tools so designers have confidence."

Besides design, the site includes a simulation tool, claimed to be accurate within plus or minus five percent, and taking under five seconds to return the results.

Simulation based on Spice models includes Bode plots and transient analysis of steady state, step inputs and step loading. The analysis includes parasitics, and can show up unwanted ringing in the circuits.

"We not only do electrical simulation, we also provide thermal and mechanical information," said Schroeder.

The tool outputs schematics and a complete bill of materials for free, while customised design kits costing $335 can be delivered within three days to European customers.

For more information visit myPower.irf.com

Wake-up to lead-free warnings

Electronics companies in the UK must wake-up to impending lead-free (Pb-free) legislation from the EU.

"It's the whole supply chain. Many companies, particularly SMEs, have not woken up to the issues. A lot of SMEs think it does not affect them and solder suppliers or assemblers will sort it out," said Soldertec's Dr Jeremy Pearce.

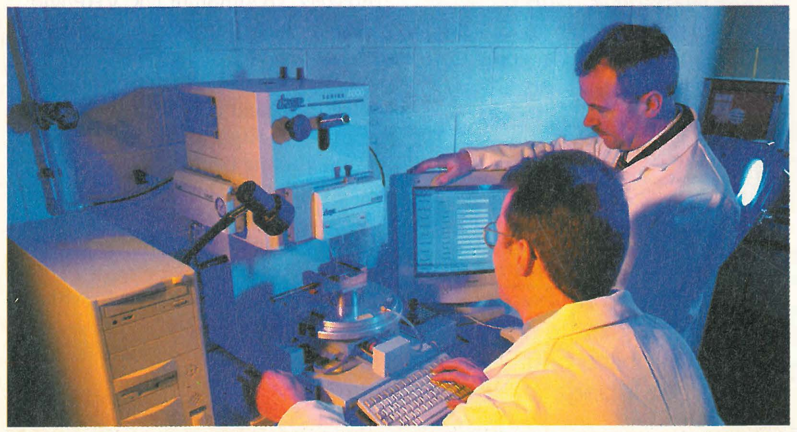
Soldertec is a tin industry body, set up to research and promote Pb-free soldering.

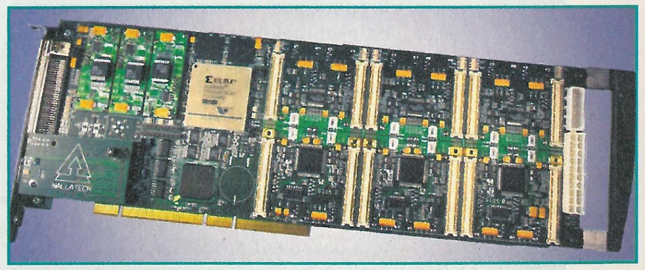
Although the Pb-free deadline has not been formally set, it will be during 2006 or 2007. After the deadline almost every piece of electronic equipment sold must be Pb-free.

Many electronics companies have no idea how to remove lead from their products. "It is not nearly as difficult as people like to imagine," said Kay Nimmo, Soldertec's director of R&D.

Free Pb-free information including EU target dates is on Soldertec's website at www.lead-free.org.

Soldertec's labs.





Programmable boards on the rise

Scottish firm Nallatech has developed a PCI-card that can hold up to seven leading edge Xilinx FPGAs, giving up to 56 million gates of programmable logic.

Dubbed BenNUEY, the board fits in a standard PC slot and has a single FPGA as standard. Extra devices are added via daughter modules.

"A lot more people are beginning to understand FPGAs, courtesy of the likes of Xilinx and Altera," said Dr Malachy Devlin, Nallatech's chief technology officer.

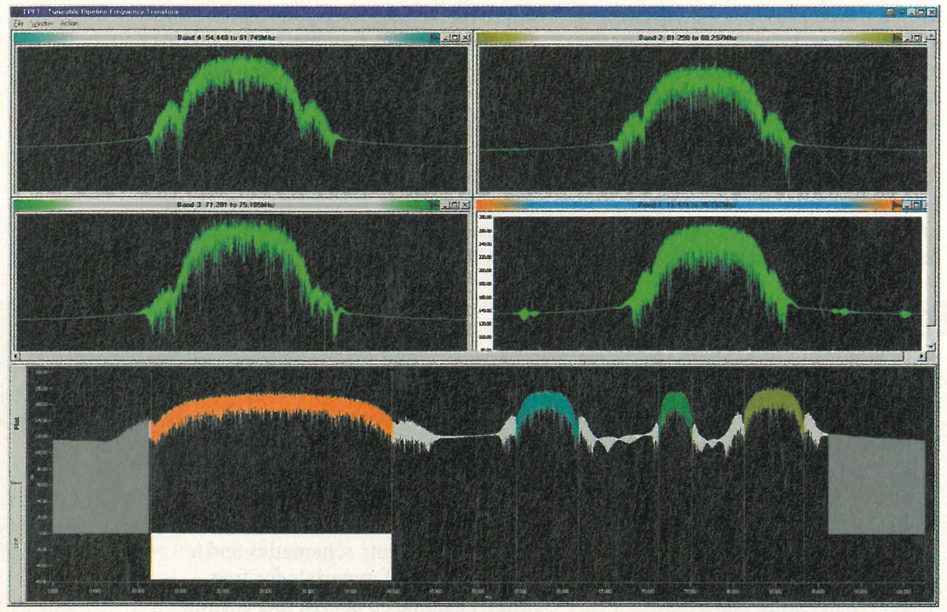
He likens the programmable logic market to microprocessors in the 1970s, it has a lot of growth yet to come. "Reconfigurable computing is just starting out," said Devlin.

The firm also has modules with Xilinx's Virtex-II Pro FPGAs, which contain hardwired PowerPC processors.

Tune into Isle of Wight

RF Engines from the Isle of Wight has developed a signal processing system that extracts multiple frequency transforms from a wideband channel. Called the tunable pipelined frequency transform (TPFT), the system can simultaneously perform several transforms on different sectors across an 80MHz channel.

The firm unveiled its basic technology last year, and the TPFT extends the concept. Both designs are programmed into a Xilinx FPGA.



"PFT essentially is a technology which slices the channel into equal divisions," said John Summers, v-p of business development at RF Engines. "TPFT allows the user to define what his channel analysis is."

Rather than analyse a complete 80MHz bandwidth, for example, the TPFT only works on areas in which the user is interested. Several different sized frequency bins can be analysed which are arbitrarily distributed across the channel.

The firm is pitching the technique against standard digital down converters.

Because the TPFT is implemented in an FPGA, the whole design can be reconfigured if different areas of spectrum need to be analysed.

One possible application could be as a power meter. Existing systems go through each channel in turn, whereas the TPFT can simultaneously check all signals within a 80MHz range.

RF Engines sees a market for the TPFT in satellite comms, instrumentation and mobile basestations.

AM/FM radios get DSP injection

AM/FM radio design could get a digital boost as Motorola announces a chipset that borrows heavily from mobile phone technology.

Called Symphony, the chipset has a fairly conventional RF front-end chip, but that is where the similarities end.

The IF chip includes analogue to digital converters that pass on the received signal as a digital bit stream to a baseband processor. This includes special purpose digital signal processors (DSPs) alongside Motorola's general-purpose 24-bit Onyx DSP core. All told the baseband chip is capable of 1.5Gips (gigainstructions per second).

Filtering and demodulation is done digitally in a series of algorithms which means filter and other parameters can be adjusted on-the-fly to get the best audio output.

Motorola claims its variable IF filter algorithm cuts adjacent station interference and a channel effects equaliser holds on to stations longer in moving car radios. In addition there are algorithms to reduce multipath interference.

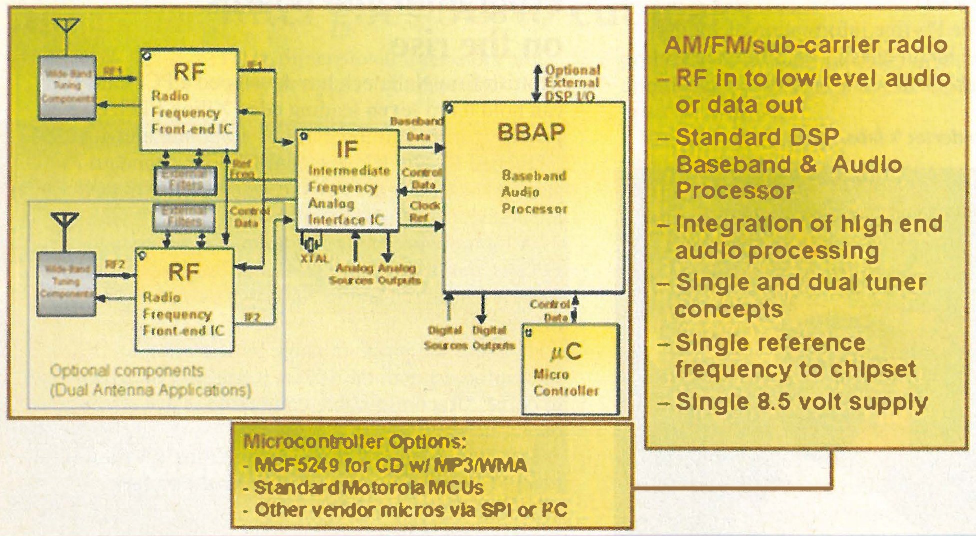
The FM demodulator algorithm, said Motorola, provides superior range extension and improved signal-to-noise ratio (SNR) under weak signal conditions. Stereo separation is "often greater than 40dB".

There is sufficient capacity in the IF and baseband chips to handle two RF front ends - allowing two channels to be received or the SNR of one station to be improved.

Unfortunately the RF front end tuning range is from 200kHz to some 160MHz, so although UK VHF and medium wave bands are covered, half the long wave band is not.

On the plus side, there is room left in the baseband chip for audio processing. Algorithms are available to add volume control, dynamic range compression, several types of tone control (including a graphic equaliser), speaker compensation and spectrum analysis.

Samples are available now, with production due in 2003.



Germans add new wireless standard

Nils Jasper, Nanotron's head of sales.

Nanotron from Germany has developed a 2Mbit/s wireless local area network protocol with 60m indoor range, even in licence-free, low power bands.

The firm's chips are based on a modulation technique it calls multi-dimensional, multiple access (MDMA). The scheme claims to combine the quality of CDMA (code division, multiple access) with the flexibility of TDMA (time division, multiple access).

MDMA chips from the Berlin-based company will squeeze into an already crowded piece of public spectrum at 2.4GHz - the industrial, scientific and medical (ISM) band.

Nils Jasper, Nanotron's head of sales, defended his company's use of the ISM band, adding: "It [MDMA] is very unique - nothing you can compare to existing systems."

The first MDMA test chips, called Nanonet TRX, will have an indoor range of 60m, while outdoors this can extend to 700m. At 2Mbit/s, the chips manage to stay within the ISM band's output power limit of 10dBm, Jasper said.

"What's even nicer is we have a standby current of below 1ΩA," he added. "And we are significantly more robust than any other transmission." He attributes this robustness to the MDMA scheme, which uses double spreading techniques.

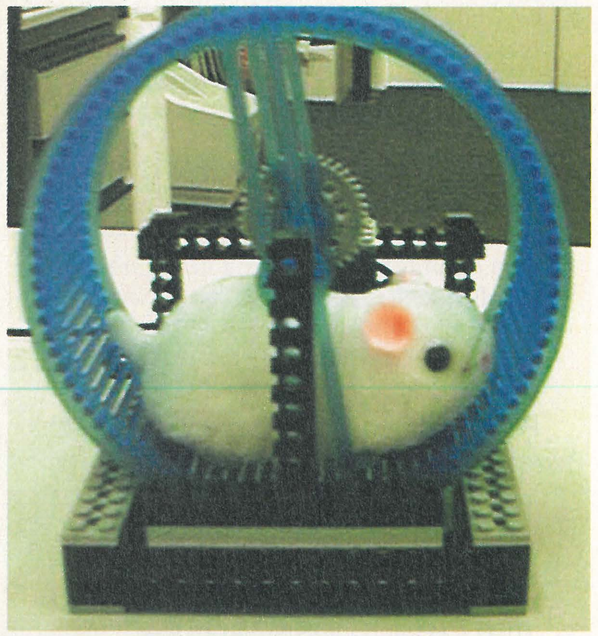
MDMA uses 'chirp' FM pulses, which makes it possible to keep average power constant, the firm said. A dispersive filter compresses the distributed energy at the receiver.

The bit error rate of the system is variable, but is set on the first chips to 10^{-3}, the same as the Bluetooth specification. It could be increased to as much as 10^{-9}, presumably at the expense of data rate or by using higher power.

In the lab Nanotron is using a standard Bluetooth aerial, although Bluetooth can only reach around 700kbit/s in good conditions. Even wireless LAN, in its 802.11b guise, only manages 4Mbit/s at a range of 10m, Jasper claimed. Wireless LAN chips are far more complex, and potentially more expensive.

Rat proves asyncronous point

Asynchronous logic can be designed to automatically make the best use of any voltage supply available. To demonstrate the point, researcher Charles Brej made this generator which produces between nothing and 1W as its electric mouse falteringly runs around.

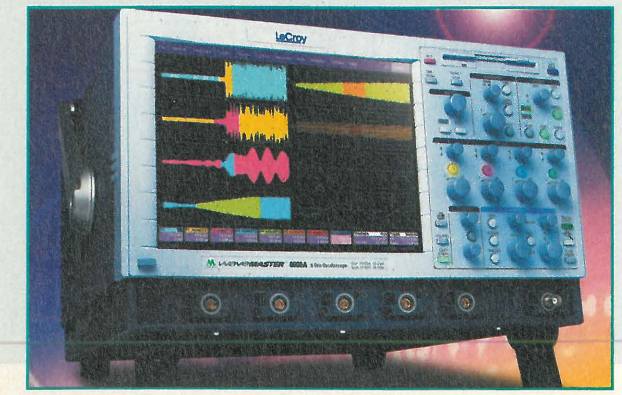


The attached Amulet 2e processor correspondingly self-throttles and offers performance from nothing to its maximum of 40Mips. Amulet power efficiency is 290Mips/W and Brej is thinking of moving from mice to rats. "A rat should be about 2W, thus a rat can generate 580Mips on Amulet2e. This is very good when compared with a processor like the Athlon which uses 60W - 30 Rats - to produce the same speed," he said.

Brej is based at the University of Manchester's computer science department which has designed a number of asynchronous processors in addition to its ARM-compatible Amulet series.

If funding can be found the department will spin-out a company called Self-Timed Electronics to exploit its expertise commercially.

Of particular interest is the department's Balsa synthesis tool which can be used to generate asynchronous logic designs from high-level circuit descriptions.



LeCroy has unveiled a digital storage oscilloscope that can capture signals with a 6GHz bandwidth and 75picosecond (ps) rise time. The WaveMaster 8600A adds to existing 5 and 3GHz versions. By using silicon germanium front end chips, the scope can sample data at 20Gsample/s, with triggering on glitches as short as 600ps, the firm said.

Batteries get charged up

Irish technology firm NTera has demonstrated lithium ion cells that can be charged and discharged 10 or 20 times faster than commercial batteries.

The firm says that while production devices are limited to 1C rates - 1A charge for a 1Ah cell - in the lab it has achieved 10C and 20C rates. NTera has been able to speed up the chemical process by using smaller active particles. Increased surface area allows lithium ions to get into and leave the material quicker, it said.

While particles in standard designs are around 10 to 30μm in diameter, NTera's work has reduced this to between 20 and 200nm.

The downside to faster rates is a reduction in overall energy capacity. Charging at 10C, giving a six minute charge time, reduces total available charge to 95 per cent, while working at 20C cuts the energy to 60 to 70 per cent of maximum.

Besides raising charge and discharge rates, the firm is hoping to improve the safety record of Li-ion cells, which hold more energy in terms of W/kg than dynamite. This is being done by changing from using carbon as the anode material, and replacing it with lithium titanate spinel ($Li_4Ti_5O_{12}$). Carbon is inherently unstable, said the firm, because material accumulated at the anode is close in terms of electrochemical potential to lithium metal.

Modern impedance measurement techniques

Since the early days of electrical science until the advent of the microprocessor, the measurement of impedance was a grubby affair. In this set of in-depth articles, Alan Bate (BEng (Hon's) MIEE) takes us through the history and future of impedance measurement.

In the early days, impedance was measured using manual balancing and later semi auto balancing bridge instruments. These instruments consisted of a network that included the unknown impedance, which was matched or balanced against a known impedance 'reference' network. The great advantage was that they were null measuring instruments: the indicator had no more to do than display zero. This enabled instruments to be made with high precision.

From this basic concept a whole range of bridge types was spawned, each specialising in measuring certain aspects of impedance. All these types are now totally eclipsed by the modern microprocessor-based 'smart' LCR instruments. These have superior performance in every aspect and are far more user friendly. This article discusses the modern approach.

The demise of the bridge

Such instruments are of course known as bridges, probably due to the balance detector. This is often a sensitive micro-ammeter 'bridged' across the two networks, **Fig. 1a**. The network arms were adjusted for balance giving a zero or null reading on the meter.

Bridges were slow and fiddly to operate. It was often not obvious for inexperienced users to determine which way to adjust the 'arms'.

A certain government establishment that I worked for in the 1960s had a sizeable room – known as the 'bridge room' – which was devoted solely to a range of such instruments for all the general impedance measurement made on site.

Each bridge was designed to cover a segment of the impedance plane. They ranged from the Wheatstone Bridge for resistance measurement at DC, to various AC types for inductance/capacitive reactance, often with a single test frequency of 1592Hz, or 10 000 radians, which made the maths simpler! **Figure 1b** shows a selection of bridge types.

The results read from the bridge dials where often in admittance form and reciprocal look up tables were provided in the operating manual to derive the required result. Such instruments operated at a fixed frequency or were limited to the audio to low RF range.

Radio-frequency bridges existed but could not measure very high or low impedances. Neither could adjustments be made to correct for the shunt impedances of the bridge itself although the ratio arm bridge had good immunity to shunt loading when balanced.

With the AC bridge, a tuned amplifier was often employed with head phones to increase the null detection sensitivity and avoid the problem of protecting the ammeter – but not the ear! A special type of display valve known as a 'magic eye' was also employed. One adjusted the bridge until the magic eye displayed a coloured band with minimum width.

Basic accuracy of the AC bridge was usually around 0.1% to 1%. DC resistance bridges have always achieved high accuracy. By careful design, the open and short-circuit errors and losses to ground can be made negligible at 'zero frequency'.

The UK bridge manufacturer Wayne Kerr eventually came up with an auto-balancing instrument. While these instruments were easier to use, they were very limited in frequency range and still fell far short of the flexibility and basic accuracy of modern instruments which no longer use the traditional bridge method.

Finally, apart from the ratio arm bridge, in circuit measurements could not readily be made due to the lack of guarding: more on this later. With the development of the modern LCR, a microprocessor-based instrument, several major improvements all came about at once:

- The result could be displayed in the most convenient and appropriate form. The microprocessor making the necessary calculations and decisions from the measured raw data.
- In circuit, measurements over a wide frequency range could be made.
- Fast repetitive measurements for high volume manufacturing became possible.
- Trim corrections could be made in the software calculations.
- A wide range of test frequencies became possible.
- A wide range of drive stimulus could be provided.
- Programmable DC bias of voltage for capacitors and current for inductors could be easily applied.
- Greater all up accuracy and stability as all unknown impedance types could be referenced to a highly accurate, stable and near pure resistor. Only resistive precision impedances are practical to manufacture in volume.

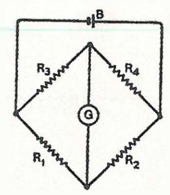
Three-terminal measurement

All modern LCR instruments and automatic test equipment, or ATE, use three-terminal measurement methods. This enables accurate in circuit measurements of impedance to be made with a simple circuit, **Fig. 2**.

If the ammeter is perfect, i.e. it has no shunt resistance, it presents a perfect short at terminal *I*. Hence even if a shunt impedance exists from terminal *I* to ground, no reading error can occur as the ammeter will 'hog' all the current, i.e. provide perfect 'current guarding'.

A perfect differential amplifier monitors the unknown voltage drop across Z_u directly at the unknown terminals *E* and *I*. The modulus of the impedance can now be derived by the ratio of the voltage to current reading. Notice that the generator source and

The original Wheatstone bridge for measuring resistance with d.c. (Fig. 7.1), from which so many varieties have evolved, is a symmetrical network of six "arms", one containing a source of current such as a



Simple Wheatstone bridge, on which all other forms of bridge are based

battery, and another a detector such as a galvanometer. When the resistances of the remaining four are in proportion, i.e.,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

(which of course is the same as $R_1R_4 = R_2R_3$ and $R_1 = R_2\ R_3/R_4$) then the two points between which the detector is connected are at the same potential, so the indication is zero. The bridge is balanced. If any three of the resistances are known, the fourth can be calculated. It is not necessary to know the actual values of three; the value of one and the ratio of two are enough. So R_3 and R_4 (say) are called the *ratio arms*. If R_1 is the unknown, to be measured, then R_2 should be a variable standard resistance. Supposing first that $R_3 = R_4$; then at balance $R_1 = R_2$. By varying the ratio $R_3 : R_4$, measurements can be made beyond the range of R_2.

In theory there is no limit to the range of bridge measurement, but in practice the sensitiveness of indication, which is greatest when the resistances of all six arms are equal, falls off the more unequal they are.

The bridge network being symmetrical, the condition for balance is not affected by interchanging the source and detector.

Fig. 1a. Basic Wheatstone bridge.[1]

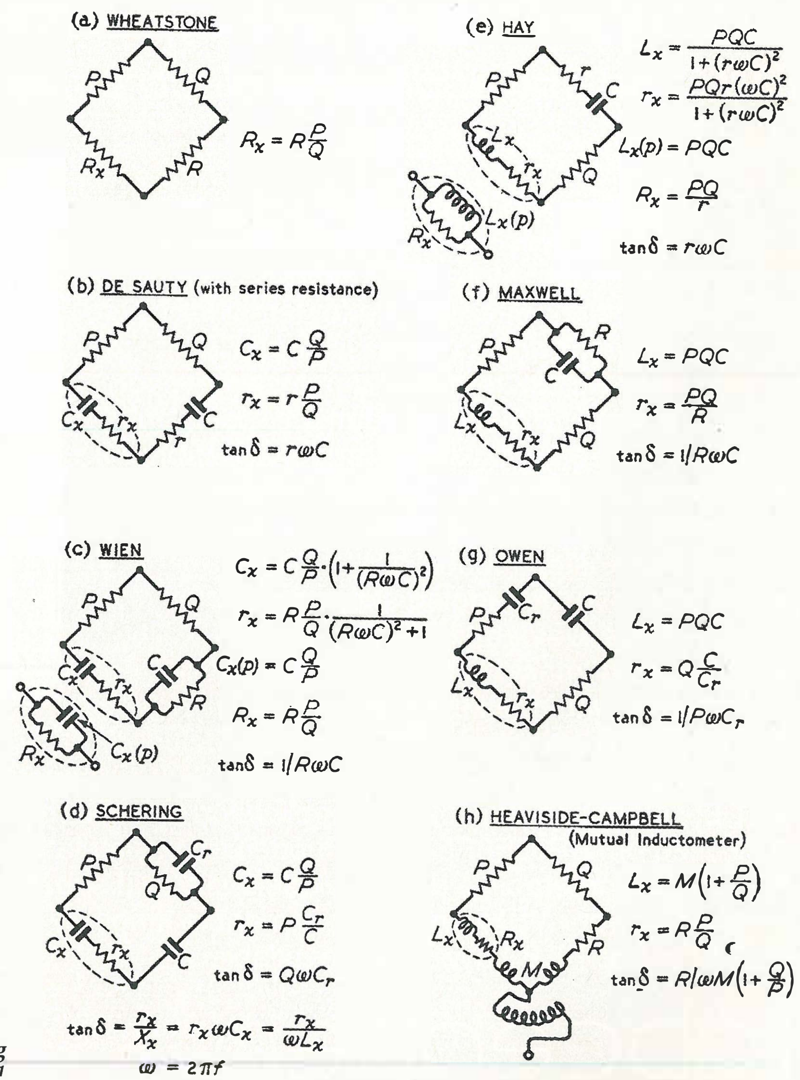


Fig. 1b. There's a variety of different bridge measuring configurations.[1]

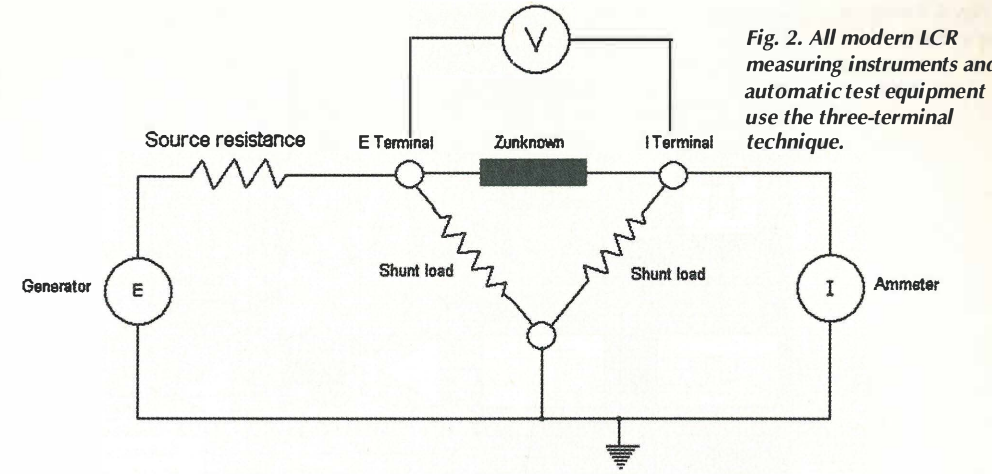


Fig. 2. All modern LCR measuring instruments and automatic test equipment use the three-terminal technique.

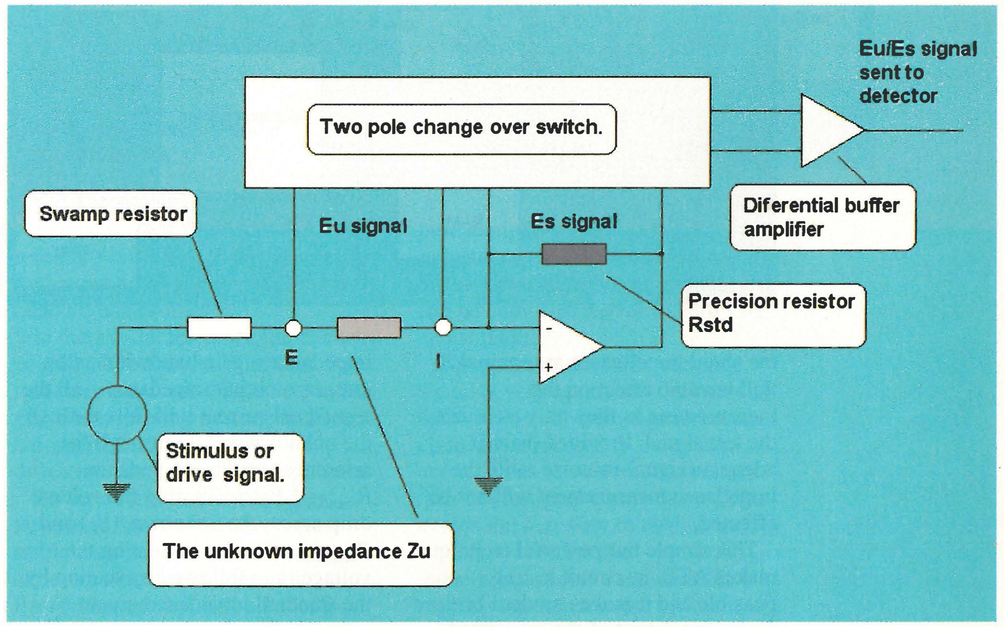


Fig. 3. Practical three-terminal arrangement using a virtual earth amplifier to guard the terminal.

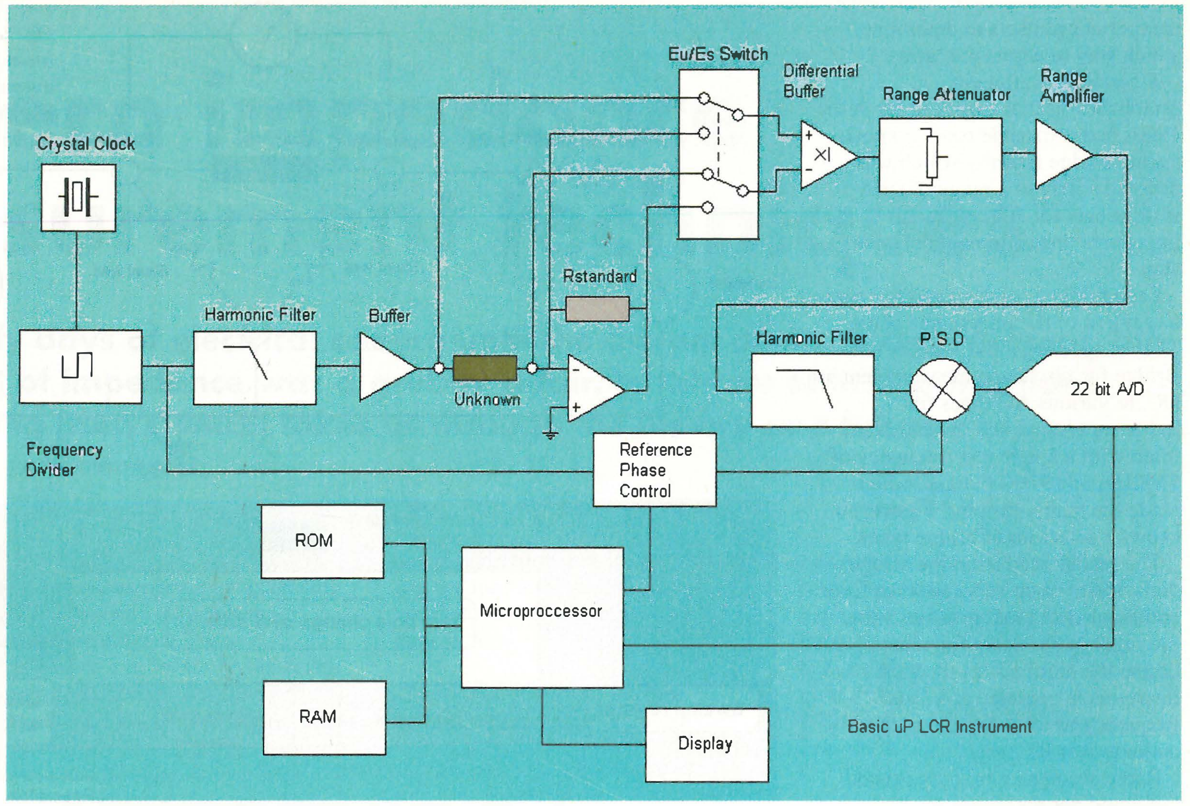


Fig. 4. Essentials of a modern LCR measuring instrument.

the shunt impedances at terminal *E* will have no effect on the measurement as they only attenuate the test signal. Provided there is adequate signal-to-noise ratio, the impedance measurement will not be effected.

This simple but powerful technique makes ATE, in-circuit testing possible and it makes modern bridges far more tolerant of the associated test circuit conditions.

To achieve the near perfect short or current guard at terminal *I*, a virtual-earth feedback amplifier is used where the feedback arm is a precision reference resistor, **Fig. 3**.

Assuming a perfect operational amplifier – i.e. infinite gain, input impedance – gain bandwidth, slew rate, zero output impedance – all the test-signal current will flow through the unknown and on through the reference standard impedance $R_{standard}$. By monitoring the voltage drop across the unknown, (E_u) and $R_{standard}$ (E_s) and calculating the voltage ratio followed by scaling by the standard impedance gives;

$$Z_{unknown} = \frac{E_u}{E_s} R_{standard}$$

One differential amplifier is used via a double-pole changeover switch, monitoring the two voltages E_u and E_s in rapid succession. This gives more than a saving of an amplifier. We are making a ratio measurement with a common meter so the total gain and phase characteristics of the meter circuits following the switch are cancelled in the ratio calculations. This makes ratioing the most powerful of all measurement techniques.

The drive signal circuitry only needs to have a very short-term stability, which is easy to achieve.

Shunt and series errors can be corrected for by making open and short-circuit readings and applying offset corrections in the software.

The range of impedance measured is extended by precision ranging. This is achieved by a combination of changing the gain before the meter circuit and on a more expensive instrument the reference impedance. More on this later.

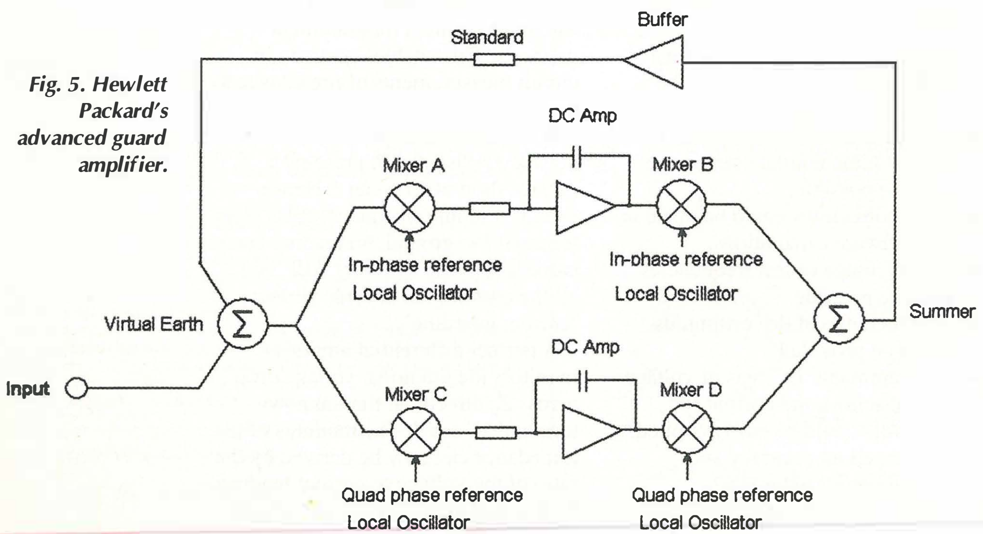


Fig. 5. Hewlett Packard's advanced guard amplifier.

The smart bridge

Figure 4 shows the essentials of a modern LCR measuring instrument. On a low-cost instrument, the sine wave stimulus is often simply generated by filtering a square wave.

The stimulus is buffered and applied to the unknown. The virtual earth or guard amplifier (as it is a current dual of a voltage guard circuit) ensures that the unknown current is passed through the reference resistance.

Signals E_u and E_s are monitored in turn by the analogue switch. Any necessary gain ranging is applied in the detector chain circuits in order to provide the optimum signal level to the phase-sensitive detector, or PSD. The PSD resolves the two signals into their orthogonal components by multiplying each signal against an inphase and quadrature reference signal.

By phase shifting the quadrature reference to + or –90°, the inductive and capacitive reactive components is obtained. The PSD output is digitised by an integrating A-to-D converter. It is also synchronised to integrate over a multiple whole number of stimulus cycles in order to reject ac ripple from the PSD output by the analogue-to-digital integrating process.

The four signal measurements are stored as 24-bit fixed-point numbers for further processing. The *a+jb* calculations are carried out in real time while the next conversion is under way. The readings are displayed in the appropriate form or as the operator selects so that if necessary a capacitor can be read as a negative inductive reactance and *vice versa*!

In auto mode, software algorithms select the most suitable way to express the measured impedance. For example, a low impure resistance would be expressed with the reactive component as a series inductance and a small impure capacitance as capacitance shunted by a high resistance.

In practice, the instrument makes six measurements per reading as the A-to-D converter DC offset of each signal is also required. Usually the system offset of the real component of E_u and E_s is measured with the PSD turned off. Normally the same offset is used for the reactive reading to avoid having to make eight measurements. More on this later.

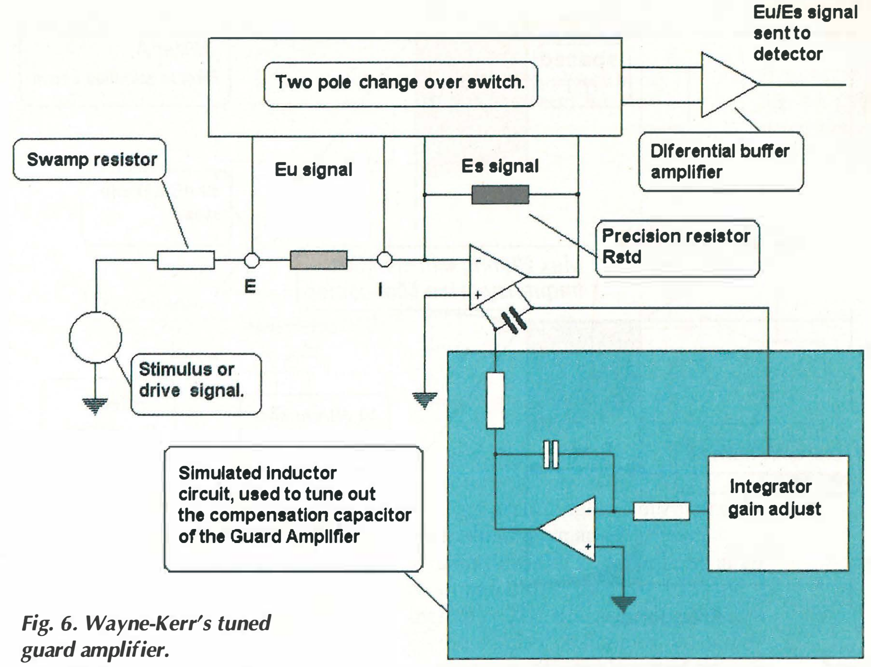


Fig. 6. Wayne-Kerr's tuned guard amplifier.

Benefits of bulk metal film

The accuracy of the whole instrument depends on the accuracy of the reference impedance and the stimulus frequency or in practice, the system quartz clock oscillator.

In theory, the reference impedance could be a reactance. With capacitor measurements, this would help in the guard amplifier by not emphasising harmonic distortion due to differentiation of the stimulus current.

However, as mentioned earlier, a far more accurate and temperature stable resistance can be made than either an inductor or capacitor. Resistors made by the bulk metal-film process – originally developed by Vishay – provides a compact component that's stable to around 2ppm/°C over the instrument operating range. They can be manufactured with tolerances of better than 0.005%.

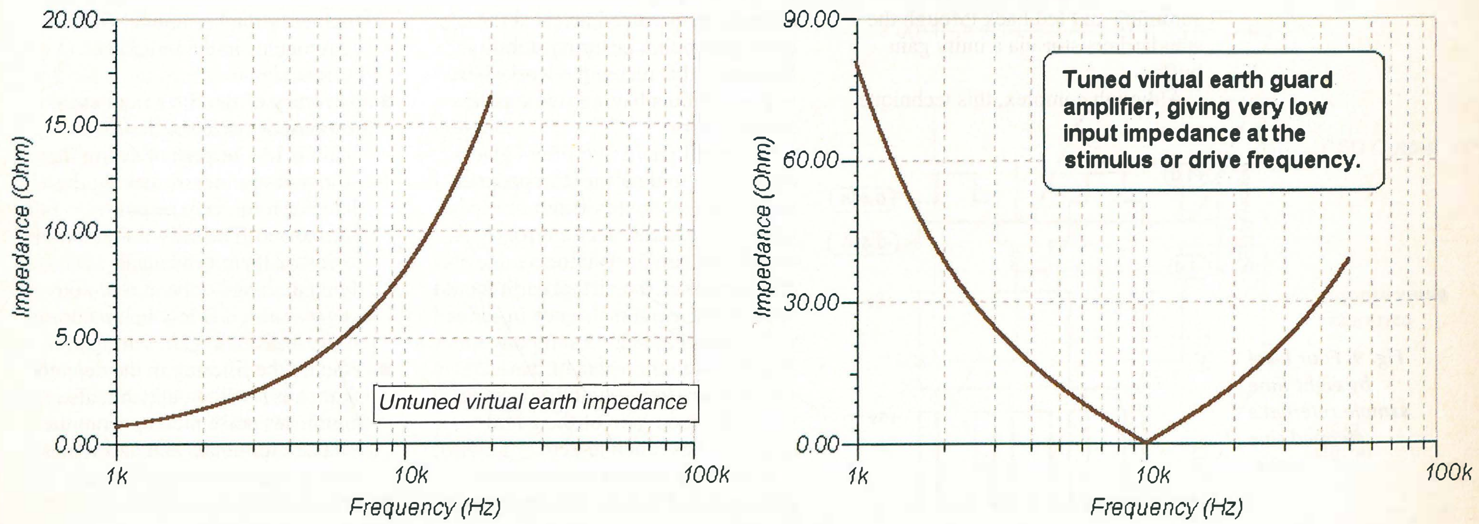
In their plastic encapsulated form, bulk metal film resistors are a very pure component with low self-inductance. The self-capacitance of the resistance is less important and can be compensated for in hardware and software.

The phase of the PSD reference signal is very accurately defined and set to 0 or ±90° with digital timing circuitry referenced to the system crystal clock to resolve the real and quadrature signal components. This avoids the necessity to change the standard resistor to an inductive/capacitive standard for reactive measurements.

Guard or super guard

The efficiency of the guard amplifier is vital to the accuracy of the instrument, particularly with increasing measurement frequency. A shunt capacitive load at the *I* terminal gives a serious scalar vector error while a shunt impedance between the

Fig. 7. Curves a and b show untuned and tuned virtual-earth impedances respectively.



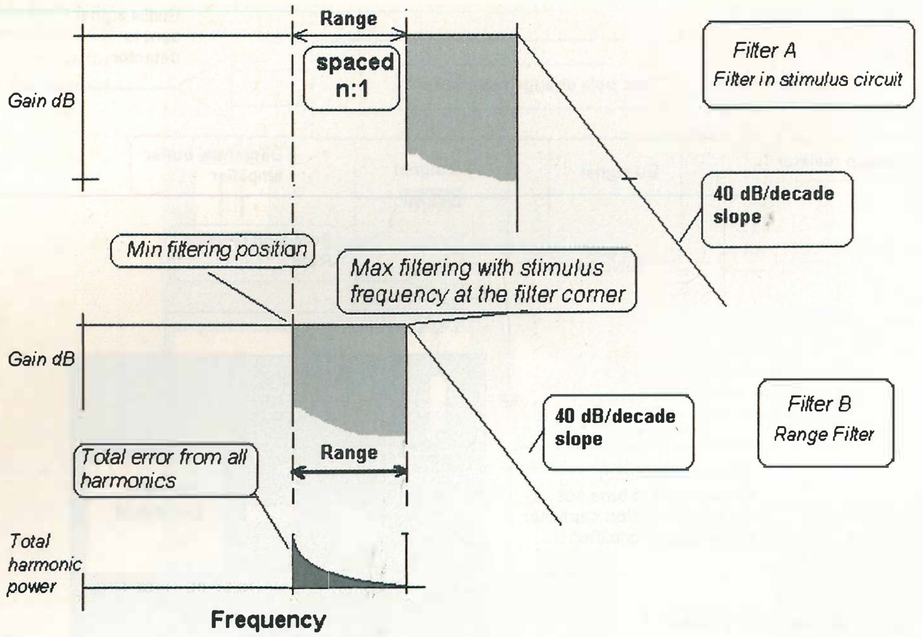


Fig. 8. Staggered filtering for wide frequency range harmonic filtering of the drive signal.

measure terminals merely gives an offset error which is easily corrected in software by taking an open circuit reading.

It can be readily seen that to maintain a good virtual earth requires an ideal amplifier having high loop gain with no internal phase shift. A great deal of effort has therefore been spent by various LCR instrument manufacturers on guard amplifier development.

A very novel but complex approach adopted by Hewlett Packard Instruments – now Infinion – used four PSDs. Here, the unknown signal current is demodulated to zero frequency or DC using two synchronous mixers to preserve the in-phase and quadrature signal components.

The two DC components are amplified by the integrator amplifiers and to converted back to the signal frequency with a second set of synchronous mixers. The orthogonal signal components are recombined by summing and fed back through the standard resistor via a unity gain buffer.

Although complex, this technique gave very good guard performance over a very wide frequency range, **Fig. 5**.

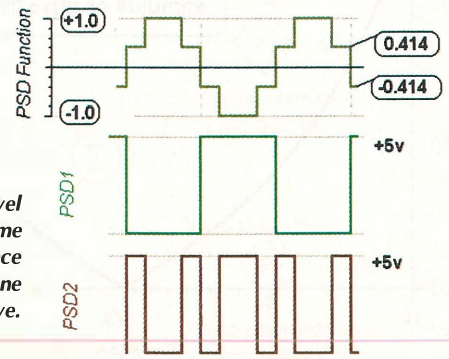


Fig. 9. Four level by eight time sample reference stepped sine wave.

What IC manufacturers don't know

Wayne Kerr enhanced its guard amplifiers on the company's WK3245 and WK6425 instruments by tuning the guard amplifier IC op-amp's internal compensation capacitor to the measuring frequency using a programmable simulated inductance circuit **Fig. 6**. This had the effect of virtually removing the presence of the compensation capacitor and raising the amplifier gain to the uncompensated loop gain at the measure frequency.

Above resonance, the loop gain returns to the compensated response, as the effect of the capacitive reactance above resonance becomes dominant. By restricting the tuning to around a decade below the unity gain point of the amplifier, the loop gain and phase margins return to the normal compensated levels at the unity gain point, ensuring stability. Naturally, this technique works best with amplifiers having single pole compensation.

The tuned guard amplifiers give a deep notch to their input impedance and effectively hold off the undesirable scalar vector error mentioned earlier. Without compensation, the virtual earth would appear as a small resistance in series with a small inductive component. This limits to the value of the standard resistor at high frequencies where the loop gain of the guard amplifier has fallen to zero.

The source must have a swamp resistance to limit the voltage gain of the guard circuit when a short circuit is applied to the measuring terminals. **Figures 7a** and **b** show untuned and tuned virtual earth impedances respectively.

Stimulus – synthesis versus servo

Sine-wave synthesis. Ideally, the sine-wave drive signal or stimulus should be a pure sine wave. In practice it should have no harmonics that the PSD could respond to. It is also very desirable with an instrument for the user to be able to select a new frequency with the minimum settling delay.

The simple approach of filtering a square wave, mentioned earlier, would require excessively complex filtering for a high performance multi-frequency instrument with the consequent settling problems of a narrow band system at the lowest measure frequencies.

By generating a close approximation stepped sine wave from a digital source, it is possible to create a drive signal with no low-order harmonics, hence, requiring considerably less filtering. The amount of filtering depends on the PSD design.

Because the PSD is an analogue multiplier, any harmonics in the reference signal will enable the PSD to respond to any associated harmonic frequencies in the stimulus. Theoretically the filtering could be applied anywhere prior to the PSD. In practice, the following considerations have to be made:

- Present to the user at the *E* terminal a reasonable looking sinwave drive signal.
- Avoid overloading the guard amplifier when measuring capacitors. It inherently differentiates or emphasises with frequency the harmonic components in the unknown current signal.
- Accuracy of the filter frequency response level in the detector chain is less important due to the ratio measurements, making the detector frequency response normalised. The only limitation is to ensure there is adequate dynamic range or head room on large signals and low noise floor at the maximum gain setting.
- Placing the filtering in the detector chain ads settling delay but also minimises noise pick up from the measure terminals and harmonics from quasi-linear components.
- The stimulus filtering needs to have a flat Butterworth response with good level accuracy in order to maintain a defined drive level setting. Filter stop-band performance is secondary to this requirement.

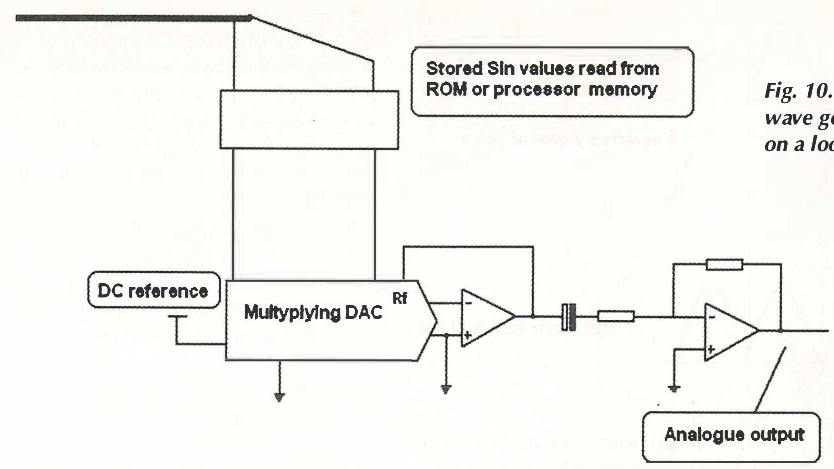


Fig. 10. Digital sine wave generator based on a look-up table.

Obviously, there is a trade off in the degree of synthesis of the drive signal and the filter degree. With a precision instrument having a basic accuracy of 0.05%, the error contribution from harmonic distortion would need to be below 100ppm for a 20% contribution to the error budget. This corresponds to around 80dB of stop-band performance at the second harmonic for a simple square wave source implying a 12th order filter over the instrument's frequency range!

Fortunately, the design problem is eased in two ways – firstly by splitting the instrument's frequency range into bands and secondly by filter hopping.

This is done by staggering the two filter stages and setting the highest drive frequency setting to coincide with the lowest filter corner frequency setting in a band. The error will be within budget, but will gradually increase as the user selects increasingly lower frequency settings. This is due to the harmonics, which are locked to the fundamental, also moving down in frequency, and becoming increasingly less attenuated as they ride up the slopes of the combined filter response.

When the total harmonic error becomes unacceptable, the initially higher filter frequency position is adjusted so that it becomes the lower filter and spaced by a geometric factor n:1, **Fig. 8**.

The maximum filtering will now apply again at the lowest frequency setting in the band. This process is repeated as the user selects increasingly lower frequencies.

This technique, possibly originated by GenRad Instruments, maintains a defined level of filtering over a comparatively wide frequency range.

Low-order harmonics, which would require a very sharp filter cut-off response, are rejected by the purity of the synthesised stimulus and PSD reference waveforms. For example, with the WK3245 and WK6425 model instruments, Wayne Kerr chose an eight level by sixteen-time sample synthesis for the stimulus. This lowers harmonics of this type of waveform either side of the sample frequency, i.e. the 15th and 17th. The harmonics are reduced to 1/15th and 1/17th or –6dB/octave.

Hewlett Packard originated a PSD reference waveform that used only two switches to generate an eight-time sample by four level waveform, **Fig. 9**. This had no harmonics until the seventh and ninth, again reduced by 1/7th and 1/9th from the fundamental.

Overall filtering is therefore complex and required software modelling to obtain the optimum filter spacing.

Servo-loop approach

While simpler, the servo-loop approach suffers from a slower response to the user at low frequencies when selecting a new frequency.

Stimulus output level is monitored and compared to a reference by an error amplifier. The error signal is used to control two or more second order voltage controlled low pass filter stages. On selecting a new frequency, the appropriate filter band is selected by the firmware.

The filter is then fine tuned by the control loop reducing the filter's corner frequency until the output level has attenuated to the reference level where the loop regulates. The attractiveness of this analogue method is the placing of the filter tolerances inside a control loop and always achieving the maximum filtering as the filter corner is always positioned at the selected measure frequency.

Using a look up table

Thanks to today's high speed SDRAM, the best method is to read sine values in binary into a fast eight-bit multiplying D-to-A converter. At low frequencies, a high number of samples are used – 256 amplitude levels and 256 time samples for example – giving a near pure sine wave and therefore requiring little filtering.

As the memory access speed is approached, the number of samples is reduced accordingly. This method today could give an eight-level sixteen-time-slot sine synthesis at up to around 8MHz by using 133MHz memory. The sine accuracy depends on the number of samples. With the distortion expressed as signal-to-quantisation noise form we get 6dB in signal-to-noise/bit. Using a table length that's a power of two, the pointing becomes simply:

Pointer address & (Table_length–1)

This limits the index to within the bounds of the table with the pointer wrapping back to the first sample at the end of a cycle. The time index is

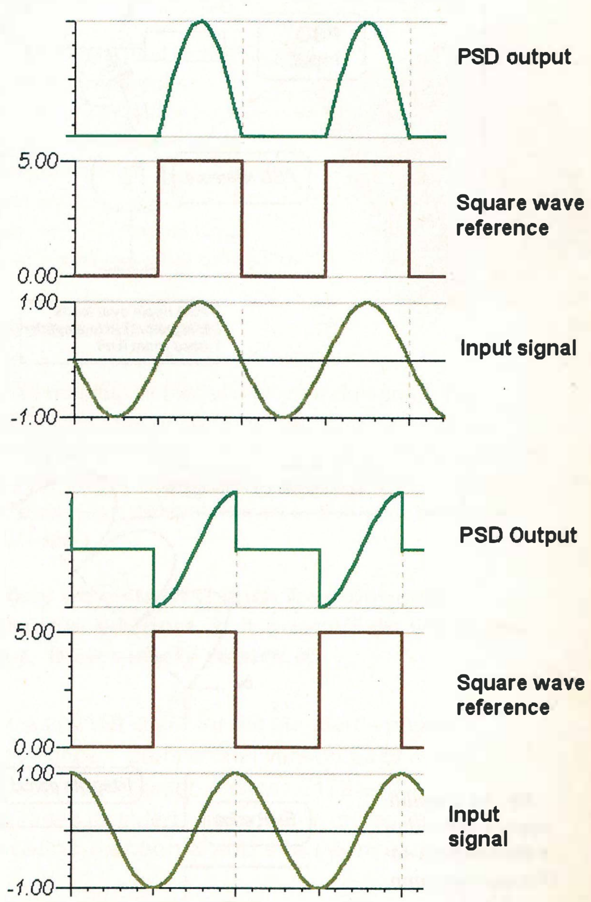


Fig. 11. Timing diagram a) shows half-wave phase-sensitive detector waveforms for an in-phase 0° situation. Diagram b) shows what happens then there's a 45° phase difference.

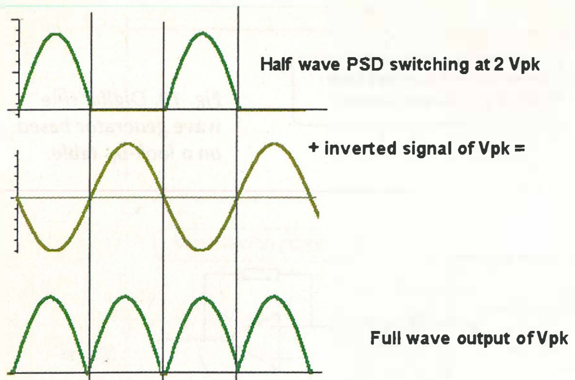


Fig. 12. Full-wave phase-sensitive detector derived from a half-wave PSD.

also bounded, removing any worry of the time pointer overflowing. With a 1024 sample table we can expect the quantisation errors to be 60dB below full scale. **Figure 10** outlines a digital sine-wave generator.

The PSD or analogue multiplier

For an LCR instrument, the phase-sensitive detector used needs to be ultra linear, with a non-linearity below 10ppm. This rules out all the conventional analogue methods. In RF mixer circuits, for example, the signals are often very small and followed by narrow-band filtering which largely rejects unwanted intermodulation products from the mixer non linearity. In fact, RF engineers are usually only concerned with the 2nd and 3rd (IP) products.

To achieve this high linearity, the only way is to apply a sampling method where the active devices operate as switches. This avoids any affects from active device non-linearity.

Secondly, the PSD must operate directly on the signal for optimum signal-to-noise performance. By integration over many whole cycles, a narrow pass band response is achieved giving very good signal recovery of the stimulus.

The simplest phase-sensitive detector

Consider the simplest PSD, which is the half-wave type, **Figs 11a** and **b**). This circuit is nothing more than an analogue switch, which is driven by a square wave, reference signal.

If the sampling signal frequency, f_{sample}, is made equal to the input signal frequency and then adjusted in phase by, say, 45° increments you would have the output waveforms shown in Fig. 11 with the average output running from $+2.I_{pk}/\pi$ to $-2.I_{pk}/\pi$. In other words, the average output is proportional to the phase difference between the input and the reference signal.

This circuit has a half wave rectified output when the input and reference signals are in phase, hence the name. The high level of ripple in the output must be rejected by the A-to-D converter in order to extract the mean DC output. This is achieved by using an integrating A-to-D process and integrating over a whole number of synchronised measure cycles.

The ability of the A-to-D converter integrator to absorb AC ripple falls with decreasing frequency and increasing integrator gain. This increases the risk of overloading at the integrate output, **Fig. 14**.

With a full-wave PSD, the ripple frequency would be doubled, giving a useful 2:1 improvement in ripple rejection. Full-wave operation also reduces the E_u and E_S switching transients by chopping up the very-low-frequency component in the transient. This full wave action is easily achieved without any extra switching complexity by feeding into the PSD output an inverted version of the input signal at half the amplitude.

The summed result is a full wave, which holds for all phase angles, Fig. 12. This works well at low audio frequencies, where it is needed most. At high frequencies, phase shift in the inverting amplifier gives less accurate addition. However, this does not matter as the shift in the output mean level is lost in the ratio measurements, and the A-to-D converter integrator's ripple rejection will have improved by 20dB/decade.■

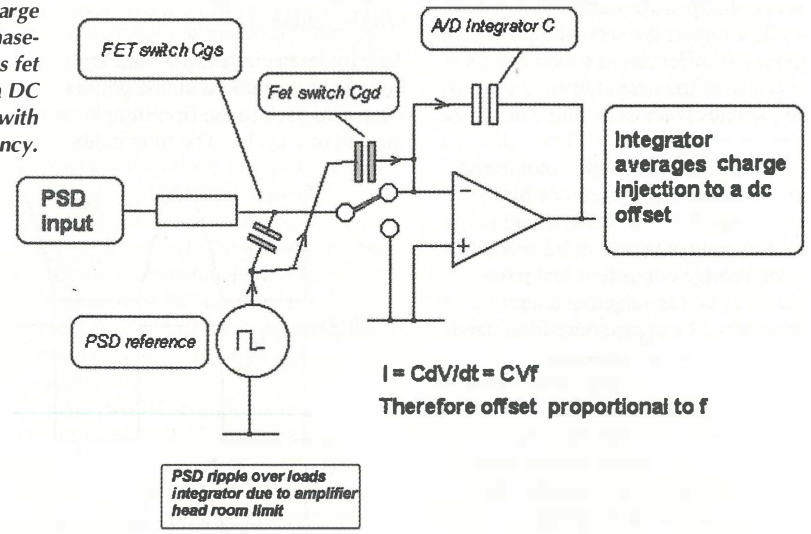


Fig. 13. Charge injected by the phase-sensitive detector's fet switches add a DC offset that grows with frequency.

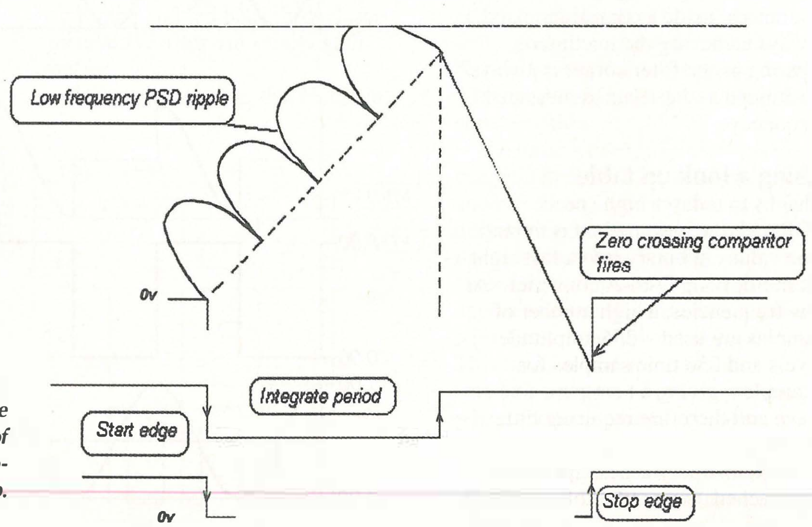


Fig. 14. Possible ripple overload of a dual-slope A-to-D converter ramp.

Reference

1. Various traditional bridges illustration: Page 230, Radio and Electronic Laboratory Handbook, M.G. Scroggie Bsc MIEE. 7th edition 1961. Published by Iliffe Books Ltd

Among the topics in the next article in this set are: ranging, calculation and display, specifying LCR instrument accuracy, adding DC resistance measurement and extending the frequency range of an Instrument. DFT/FFT and future developments in LCR measurement are also discussed and there's a review of A-to-D converters.

Part 2

RF Auto-transformers - Transmission Line Devices modelled using SPICE

Nic Hamilton (G4TXG) shows how to model the effects of a ferrite core and puts the finishing touches to a SPICE model of the RF auto-transformer. The model is used in a moderately accurate SPICE simulation of the auto-transformer measurements.
In part 2 we will be modelling the core and winding losses.

Referring back to part 1, R_P in Fig 1 represents the core loss, and L_P the winding inductance. These components are not constant with frequency, and are connected by the Kramers Kronig relations (see box). Sometimes R_P and L_P can be deduced from the published characteristics of the ferrite core material. Sometimes there is no option but to deduce the material's characteristics from measurements.

The order code for the Siemens-Matsushita B62152A8X30 cores looks complex. This is what it means; B62152 refers to the double-aperture core type, A appears to be a revision code, 8 refers to the core size, X is a packing letter (in other core shapes, this letter would specify the tolerance), and 30 refers to the N30 grade ferrite of which the core is built.

Size 8 double-aperture cores are the smallest in the range: 3.6x2.5x2.1mm and a 0.8mm hole diameter. The data book gives a number of magnetic characteristics for size 8 cores, but the one used here is $\Sigma l/A$=1.78mm-1. $\Sigma l/A$ is the core factor, and is given as C_1 in some manufacturers' data books.

The core material's series permeability

N30 grade ferrite is a medium Q MgZn material that is intended for use in broadband transformers, and has a high initial permeability μi=4300±20%. I have found this material to be among the best for broadband transformers. **Fig 13** reproduces the graph in the manufacturer's data book. I have also included an indication of the frequency range over which the material is usable.

An inductor built using an N30 core at 1MHz would have a Q of 1, so would not be much use. At 10kHz, the core would allow the inductor to have a Q of up to 100, but winding loss would reduce this to a much smaller value. It would be better to use a material with greater permeability in order to achieve greater inductance for the same winding loss. Between these limits, the inductor will have its greatest Q. On these grounds alone, the material for inductor cores must be chosen with great care. Add to this the various saturation flux densities (how much power the core will handle) and the wide range of variation of material characteristics with temperature (some materials are highly non-linear), and you have the reason for the great number of different core materials available for inductor cores.

Fig. 13. Complex series permeability spectrum of N30: a MnZn ferrite material.

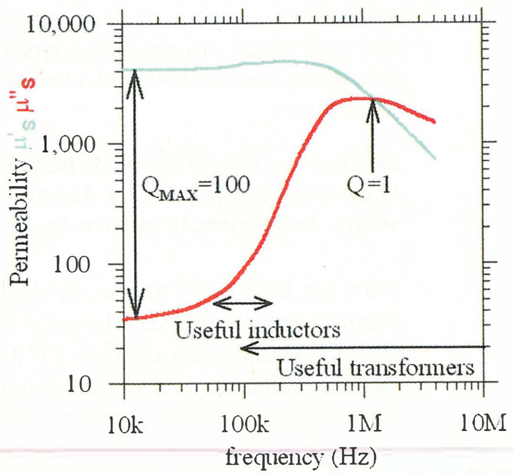
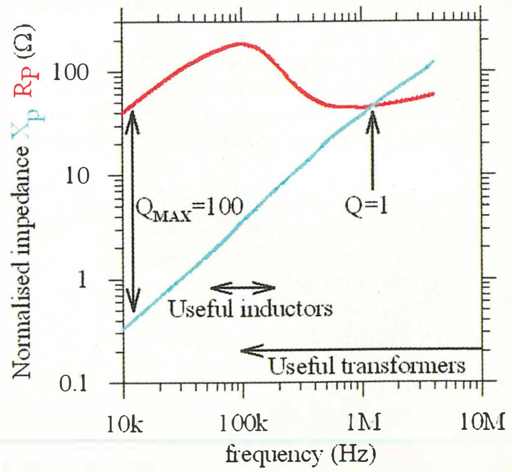


Fig. 14. Parallel impedance spectrum of N30 (core factor normalised to C1 =1mm-1).



Core material for transformers

On the other hand, the sole function of the core in the transformer is to ensure that each turn approximates to an open circuit. It does not matter that the material Q sinks to less than 1, as long as the impedance is high. So a transformer core may cover a wide bandwidth. This is the reason why there are far fewer transformer core materials on the market compared to inductor cores.

There are several problems with the data in Fig 13.

a) The data are usually measured on a ring core, and no guarantee is given of its applicability to other core shapes. The tolerance is very wide: (30% is not uncommon.

b) European data are given in terms of series permeability. Parallel permeability is needed to calculate the parallel components R_P and L_P.

c) For a wideband transformer, data may be needed up to 1GHz. Manufacturers' data seldom extends to a high enough frequency; in this case there are no data above 4MHz.

The core material's permeability converted to parallel components

Fig 14 shows the same data as Fig 13, but re-plotted in terms of parallel components[9]. The transformation from series to parallel components preserves the values of Q at any given frequency. Fig 14 provides an LF starting point, but the high frequency data is missing. The missing data can be supplied by measuring a sample, and assuming that the variability is not too great. It can also be extrapolated using an assumed value of normalised RP. For this, use a typical value of 40Ω for MgZn and 60Ω for NiZn ferrite. Both these approaches lead to uncertain results, and therefore neither leads to a satisfactory design in the spirit of ISO9001. Manufacturers could do more.

Broadband measurements

I chose to measure the material. I took one of the cores, and wound a choke consisting of 8 full turns of wire. I would then have measured R_P and X_P using a vector network analyser if I had had one. Instead, I measured the insertion loss caused by connecting the choke first in series, and in parallel with, a 50Ω circuit. From these two loss measurements, R_P and X_P may be deduced[10]. I repeated the measurement at many frequencies. The results are shown in **Fig 15,** which is provided with axes that show both measured and normalised values. The normalised values assume that there is just one turn of wire, and that the core factor C_1 is 1mm^{-1}. In this case N=8 turns and C_1=1.78mm^{-1}, so measured and normalised values are related by $N^2/C_1=8^2/1.78=36$. Also shown are the values from Fig 14 they are clearly inaccurate.

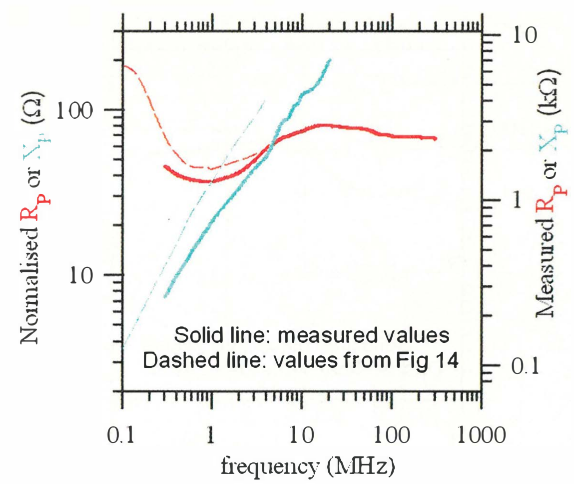


Fig. 15. Measured spectrum of RP and XP due to 8 turns on an N30 core.

It is possible to build networks of passive components that reproduce the impedance spectrum of any material; see the box on Kramers-Kronig relations. The more complex the curves, the more the time and ingenuity this takes. To model an inductor's core material, it is important accurately to model the variation of RP near its maximum. In the N30 material this occurs at 100kHz. However, for a transformer material, once the Q has exceeded 20 or so, further increases of Q have little effect on the transformer's performance.

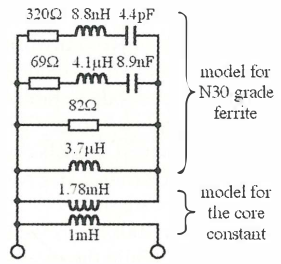
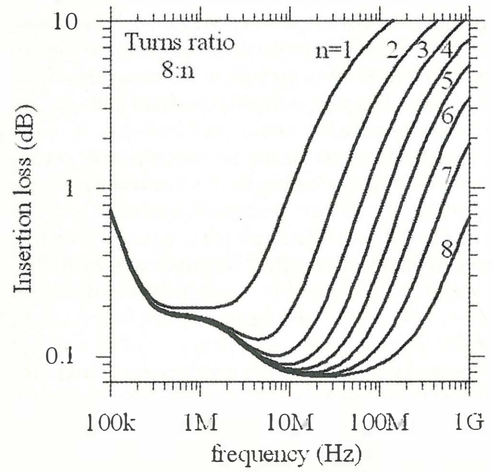


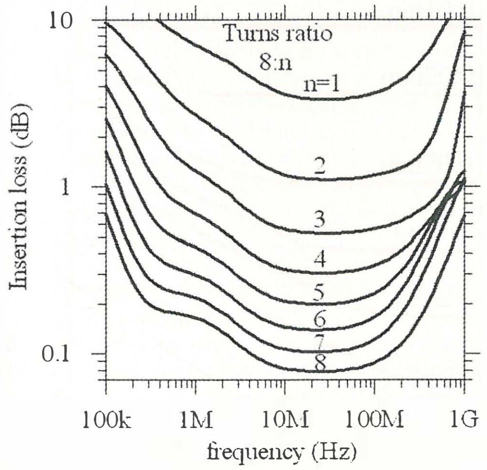
Fig. 16. Model for a B62152 A8 X30 ferrite core (use from 100kHz to 1GHz).

Building a SPICE model for the core

Therefore, the model proposed here does not accurately model R_P below 300kHz, and this greatly simplifies the equivalent circuit. The resultant model is shown in **Fig 16.** X_P is modelled by the 3.7μH inductor, and R_P by the 82Ω resistor. The two series RLC circuits model the dips in RP around 1MHz and 100MHz. The circuit was chosen as being suitable to give the correct shape, and the values were optimised using SigmaPlot®, but Mathcad® or any other programme with an optimisation facility would do.



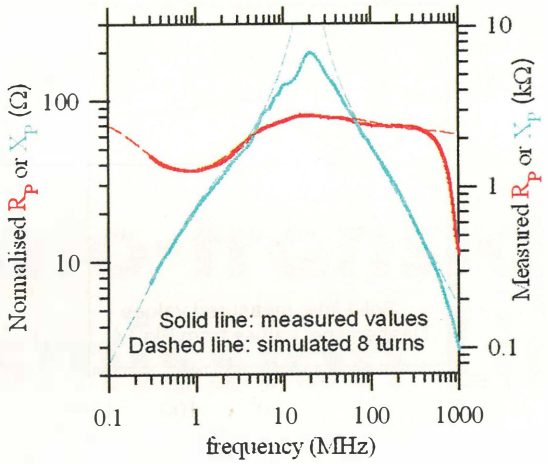
a: loss of a step-down transformer.



b: loss of a step-up transformer.

Fig. 17 Simulated spectrum of the model in Fig 11 with the core loss model of Fig 16. The simulation may be compared with the measurements shown in Fig 8.

Fig. 18. Measured and simulated spectra of RP and XP due to 8 turns on an N30 core.



Manufacturers of RF transformer cores could do designers a service by publishing models similar to Fig 16 for their materials. Such models should include component tolerances to allow Monte Carlo simulation of the material. More sophisticated models could predict the change in the ferrite's characteristics as a result of changing temperature.

In Fig 13, I state that N30 material may be used for inductors near 100kHz as well as for wide-band transformers. While the model in Fig 16 is OK for predicting transformer loss, it will give wildly inaccurate results if it is used to predict the Q of an inductor.

Take the simple transmission line model of the transformer in Fig 11, and connect the core model of Fig 16. Take two of these models and connect them back-to-back as in Fig 7. The simulation results are shown in **Fig 17,** which can be compared with the original measurement in Fig 8. The model simulation shows fair agreement with the measured results, but the model remains inaccurate in two areas:

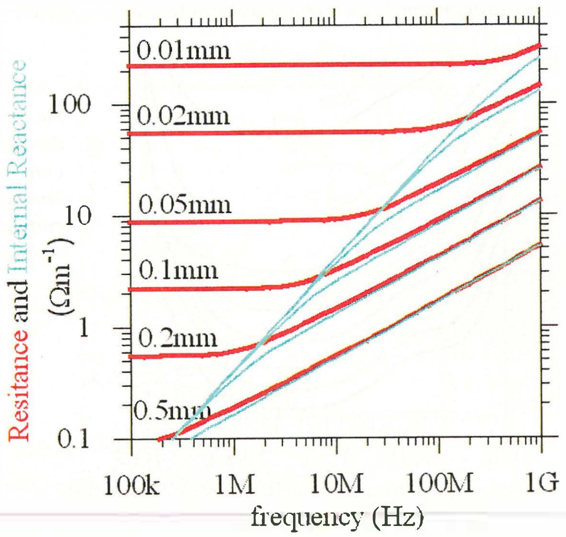
a) at high impedances the simulated loss in the HF region is too small. This is caused by ignoring the effects of winding capacitance.

b) at low impedances the simulated mid-band loss is too small. This is caused by ignoring the effects of the winding loss.

Effects of winding capacitance on measurements

Earlier, I discussed core loss, and Fig 15 showed the measured spectra of R_P and X_P for an 8 turn winding.

Fig. 19. Spectrum of resistance and internal reactance of single straight round cross-section copper wires in free space.



However, I cut the curves short at the high frequency end because this showed an effect that was not due to the core material. The full curves are shown in **Fig 18.** The positive gradient of X_P at frequencies below 20MHz indicates inductive reactance, as is expected from an inductor. But the negative gradient of X_P above 20MHz indicates capacitive reactance and this is caused by the winding capacitance shown as C_W in Fig 1. Near 20MHz, the two reactances resonate, and XP must be infinite at one frequency in this region; the simulated spectrum of XP shows this. However, the measurement shows a peak value of XP=6kW at about 20MHz. This peak is an artefact of the measurement technique, which becomes less accurate as XP/RP (=Q) becomes smaller than 1.

In an attempt to find the total capacitance, I chose a point on the curve that is in the centre of the capacitive area, say 100MHz. Here the measured X_P is 1.83kΩ, so C_W is $1/\omega X_C=1/(2\pi x10^8 x1800)=0.87pF$. The changes in core impedance contribute a little towards the overall capacitance, so the actual value of C_W must be slightly smaller than 0.87pF. Adjusting the SPICE model for best fit to the data in Fig 18 results in C_W=0.55pF, and this is the value used in the simulated results shown as the dashed line in Fig 18. However, the actual best HF fit to the data occurs at C_W=1.3pF, and this is the value I have used in the final simulation to be shown later. It seems that it is best to measure C_W at a working impedance greater than 50Ω. This small capacitance has little practical effect on the amplitude response of the step-down transformer, but it is the dominant factor in determining the HF region of the step-up transformer. I find this part of the SPICE model unsatisfying because this capacitance is the sole remaining lumped element left from Fig 1, and because I have been unable to make an informed guess as to this capacitor's value.

Effects of winding resistance

All that remains is to model the winding resistance, R_W in Fig 1. I have left it to last for two reasons. Firstly, it is the most complex part of the model. Secondly, for the transformers I have described, R_W is only important when the secondary impedance is 10Ω or less. This means that the effects of R_W appear in only a small number of graphs. However, R_W is of prime importance in transformers for matching the low output impedance of RF power amplifiers to 50Ω. It is thus well worth trying to understand the effects that influence R_W.

So far, the only important dimension of the wire has been its length and this has determined the delay of the transmission lines. However, I have ignored the wire's diameter; this will be important from here on. I used 'Road Runner' wiring pencil wire because it is available in four different colours of 'quick soldering enamel' polyurethane insulation. It has a conductor diameter of 0.192mm (36 SWG (British)); this is thick enough to be reasonably sturdy and visible. It is also available on small and relatively inexpensive reels. At dc, the wire has a resistance of 0.591Ω/m, so the total dc resistance of each transformer is 0.049Ω, including the 8 turns and the connecting wires. At RF, the resistance is greatly increased due to the skin effect and the proximity effect. There has been plenty of research[12] on these subjects, but little of it seems to be applicable to small RF transformers.

Skin Effect

The red curves of **Fig 19** show the resistance spectrum of 1 metre of copper wire of various diameters suspended in free space. The curves also apply to the inner conductor of a coaxial cable. A wide range of diameters is shown. The thickest wires are appropriate to the inner conductors of

38 SWG diameter 0.152mm		36 SWG diameter 0.193mm		30 SWG diameter 0.315mm	
R (Ω)	L(nH)	R (Ω)	L(nH)	R (Ω)	L(nH)
1.31	86	0.83	90	0.31	92
5.8	35	3.4	36	1.30	40
16.9	12..5	9.9	11.1	3.7	14.4
32.4	1.95	22.5	1.81	10.6	6.0
				16.9	0.92

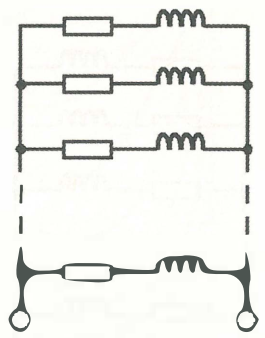


Fig. 20. Skin effect in 1 metre lengths of wire, modelled using SPICE ladder network. The 36SWG circuit reproduces the lower set of curves in Fig 21. Useful up to 1GHz.

coaxial cables. The thinnest are about the diameter of bonding wires connecting integrated circuit chips to the packages; 0.0375mm wire is common today, and the pressure is to go ever finer towards 0.0125mm.

At low frequencies, the wire's resistance is due to the resistivity of copper. As the frequency is increased, there comes a point where, due to the skin effect, current ceases to flow in the centre of the conductor. At higher frequencies, the current flows only in the surface of the wire, and the winding resistance increases at a rate proportional to $\sqrt{f}$.

Associated with the changing resistance is a changing reactance (see box on Kramers Kronig relations), and this is represented by the blue curves in **Fig 19.** These represent the internal reactance of the wire due to the portion of the magnetic flux inside the wire. For a given wire thickness, the resistive component approaches the reactive component at high frequency. Note that there is also a reactance due to the magnetic flux outside the wire, so the blue curves do not represent the total reactance of the wire.

SPICE is not good at modelling distributed components. It is therefore fortunate that the winding losses are most significant at low frequencies; this allows the use of a lumped element model with negligible loss of accuracy in the overall transformer response. **Fig 20** shows a lumped-element model that re-produces curves of the sort shown in Fig 19. Fig 20 claims that the model is accurate to 1GHz, and so it is. But in using the model at 1GHz, bear in mind the limitations of using lumped elements to represent distributed losses. These were discussed in Part 1: the model is only valid when the wire length is short compared with a wavelength.

If the model is to be used for lengths of wire other than 1 metre, and the correct dc resistance is essential, all the component values in the model must be adjusted by the appropriate factor. But for this model, the dc resistance is not is not necessary, because the SPICE transmission line model does not conduct dc anyway. Therefore the length can be more conveniently modelled by using a SPICE perfect transformer, where the wire length is set by the transformer's inductance ratio.

So far, so good. But the model in Fig 20 is only useful for the skin effect in the connection wires. Inside the transformer, the proximity effect takes hold, and this adds the final layer of complexity.

It's never as easy as that! Introducing Proximity Effect

I have presumed that readers of *EW* know something about the Skin Effect. In this, the currents in the wire cause a magnetic field that then concentrates the current flow in the surface of the wire. However, the current in one wire also affects the distribution of the current flow in its neighbour. This is the Proximity Effect.

If RF currents in adjacent wires are in anti-phase, the

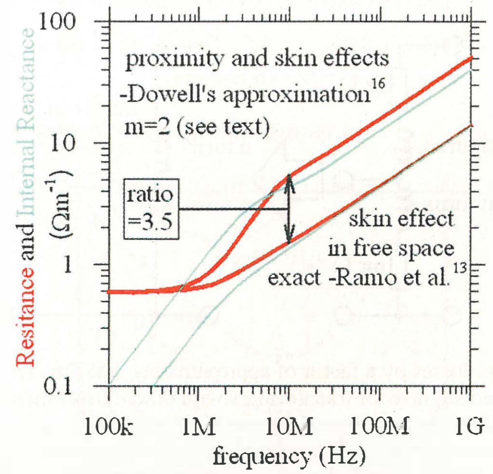


Fig. 21 Additional loss due to proximity effect in a 36SWG copper wire in a transformer.

opposing currents attract each other, and the current tends to flow on the side of the wire nearest the companion wire. This increases the RF resistance of both wires, because the current flows in a smaller cross-sectional area of the wire.

Conversely, if the RF currents in adjacent wires are in phase, the current tends to flow on the side of the wire away from the companion wire. When the currents in parallel wires are attracted to flow nearest the companion wire, the current flow is concentrated in a smaller area of the wire than if the currents are repelled to flow in the on the side of the wire away from the companion wire.

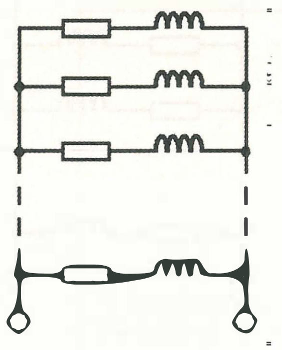
So, if the currents are in anti-phase, the loss resistance is higher than if the same currents are in phase.

Fig 19 shows the impedance of straight wires in free space, but the inside of a transformer is not free space, and the conductors are not straight. Furthermore, there are also adjacent conductors carrying large currents. Consequently, the high frequency impedance of the wire will be further increased by the proximity effect. Dowell's approximations[16] predict the combined skin and proximity effects, but they apply to pot core transformers with layered windings on bobbins, rather than for balun cores threaded with a small number of turns. The irregularity of the windings as shown in Fig 10 precludes the accurate estimation of the proximity effect. It would be interesting see a 3D electromagnetic simulator's predictions of this. In any event, I had to measure the proximity effect in my transformers.

Measuring Proximity Effect

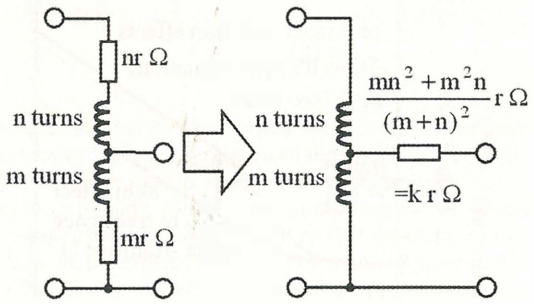
To measure the winding loss in a transformer, it is customary to measure the transformer's impedance with one winding shorted. I took the 8:1 transformer, shorted the 1 turn, and measured the primary impedance 10MHz using a vector voltmeter and return-loss bridge, and performing an open/short/50Ω. The result, after some sums, showed that the proximity effect raises the skin

Fig. 22. Proximity and skin and effects in 1 metre lengths of wire modelled using SPICE ladder network. Values derived from Dowell's approximation, m=2. The 36SWG circuit reproduces the upper set of curves in Fig 21. Useful up to 1GHz.



38 SWG diameter 0.152mm		36 SWG diameter 0.193mm		30 SWG diameter 0.315mm	
R (Ω)	L(nH)	R (Ω)	L(nH)	R (Ω)	L(nH)
1.00	178	0.626	227	779	0.328
25.3	71.7	15.4	93.1	676	0.621
79.6	25.5	52.0	34.1	118	5.75
113	0.00	76.4	2.59	34.3	20.8
				6.94	72.3
				6.94	213

Fig. 23. Referencing the winding loss to the transformer's secondary connection, assuming a loss resistance of r W/turn.



effect losses by a factor of approximately 3.6. This result varied slightly for transformers with other turns ratios because of the differing current distributions in the turns, and because the skin and proximity effects become less significant as the secondary impedance increases, so the accuracy of the measurement becomes less.

Dowell's approximations use m as a prime input parameter, where m represents the number of whole layers in a winding portion as a prime input parameter. It happens that if sensible values are supplied for all the input variables, and m=1, the resultant curves for the loss resistance are within 21% of the free space skin effect values. As m is increased, the proximity effect factor increases. If m=2 the proximity effect factor at 10MHz is 3.5, and at infinite frequency is 3.65. So m=2 is a reasonable fit to the measurement. In **Fig. 21**, the free space skin effect values and the m=2 proximity effect values are compared. Fig 21 shows the reason for measuring the proximity effect at 10MHz. Below 10MHz, the skin and proximity effects have not achieved their full high frequency gradient. On the other hand, above 10MHz the transformer losses rise due to the electrical length of the windings, and make the measurement less accurate. I know that this represents a bit of a 'think of the number you first thought of and multiply it by 3.5' solution, but I think it represents the best that I can do. The resulting model is shown in **Fig 22,** together with some estimated values for 38 and 30SWG; treat these with caution - I have not tested them.

Gathering the winding losses in one place

Assume that the loss resistance in each turn of the transformer is rW. In an auto-transformer with a high turns ratio, it turns out that the transformer loss is overwhelmingly due to the loss of the 'secondary' winding represented by the m turns in **Fig 23**. So the error of assuming equal loss resistance in each turn is low.

Clearly, it is possible to model the loss in each turn and connection wire separately. Fig 23 shows how these losses may be gathered together into a single equivalent resistor (or ladder network). The value of k varies with the turns ratio and the number of turns. But, for transformers with less than 10 turns, k lies between 1.5 and 2 irrespective of the turns ratio.

So, as a short cut, it is possible to calculate the equivalent ladder network for 1.8 turns, and use this irrespective of turns ratio.

Fig 24 shows a version of the final SPICE model for the transformer. Much of the complexity is due to the modelling of skin and proximity effects. I said in part 1 that the connection length was about 6mm. In fact, the length of the 36SWG wire was less than this, but the transformers were mounted in test jigs made of IC sockets, and which plugged into a further IC socket. The connection wires to the ends of the model therefore has a 4mm connection length, but a delay corresponding to 9mm.

I formed the connection to the centre tap of the transformer by twisting the two wires and soldering them close to the transformer body. As an approximation, I used two connection models in parallel, but a new model of skin effect in the thicker soldered wire could be constructed.

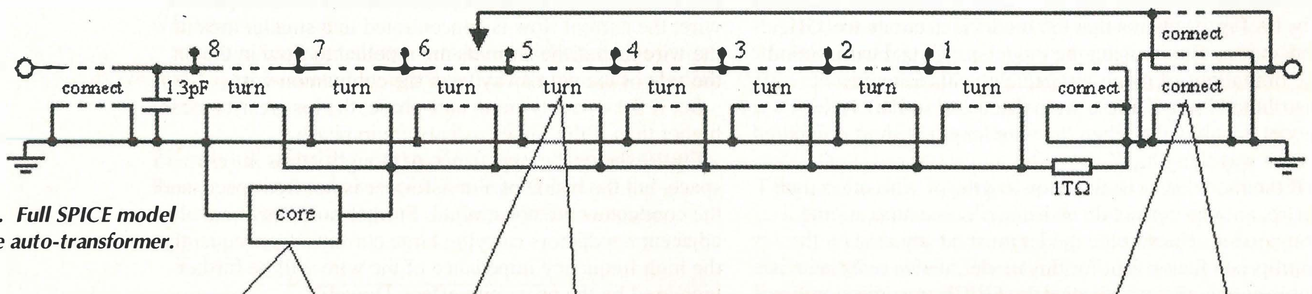
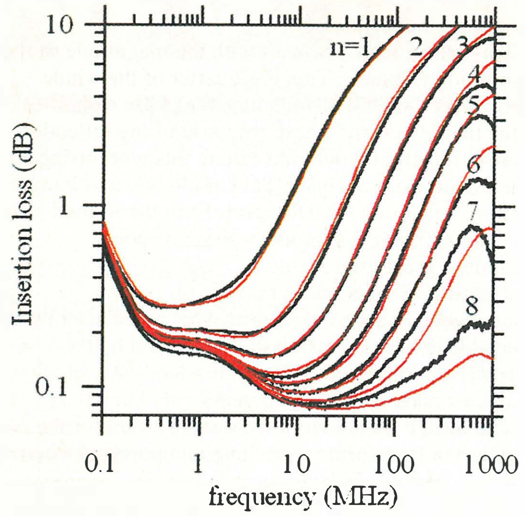


Fig. 24. Full SPICE model of the auto-transformer.

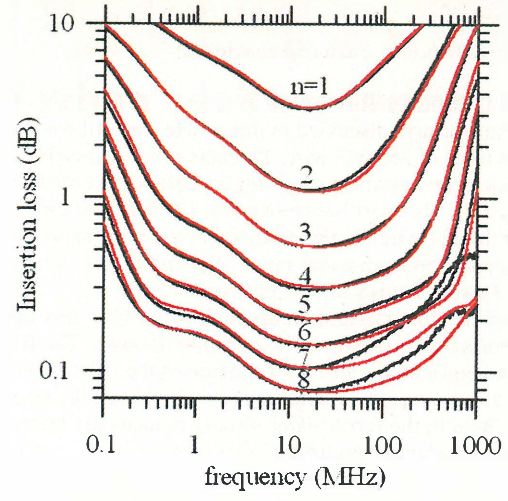
```
* Siemens B62152A8X30
* ferrite core
* has C1=1.78mm-1
* mean turn length
*  on full core≈8.9mm
.Subckt A8X30 N1 N2
L1 3  4  3.7uH
R1 3  5  69R
R2 3  4  82R
L2 5  6  4.1uH
C1 6  4  8.9nF
R3 3  7  320R
L3 7  8  8.8nH
C2 8  4  4.4pF
R4 4  9  1uR
L0K1 10 N2 1mH
L1K1 9 3 1.78mH
K1 L0K1  L1K1  1
R5 10  N1  1uR
R6 4  0  1TR
.ends
```

```
* model for a turn of 36SWG wire
* including proximity effect
* derived from dowell m=2
.subckt 1_turn_m=2 n1 n2 n3 n4
T1 n1  n2  12  n4  Z0 = 100R
+ F = 2.5e8  nl = 0.009
* nl= turn length in metres
R1 12  5  .626R
L1 5  11  227nH
R2 12  7  15.4R
L2 7  11  93.1nH
R3 12  8  52.0R
L3 8  11  34.1nH
R4 12  9  76.4R
L4 9  11  2.59nH
L0K1 12 11 1m
L1K1 12 n3 0.009m
* L1K1= turn length in metres
K1 L0K1  L1K1  1
.ends
```

```
* model for 36SWG connection wire
* including skin effect
.Subckt connection N1 N2 N3 N4
T1 N1  N2  12  N4  Z0 = 150R
+ F = 2.998E8  nl = 0.009
* nl=line length in metres
R1 12  5  8.3R
L1 5  11  90nH
R2 12  7  3.4R
L2 7  11  36nH
R3 12  8  9.9R
L3 8  11  11.1nH
R4 12  9  22.5R
L4 9  11  1.81nH
L0K1 12 11 1mH
L1K1 12 N3 0.004mH
* L1K1=36SWG wire length in metres
K1 L0K1  L1K1  1
.ends
```

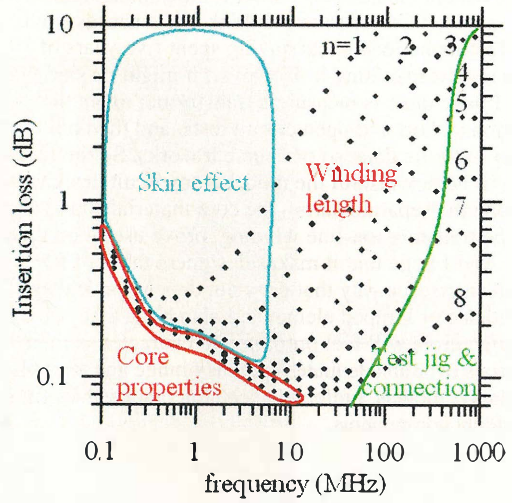


a: loss of a step-down transformer.

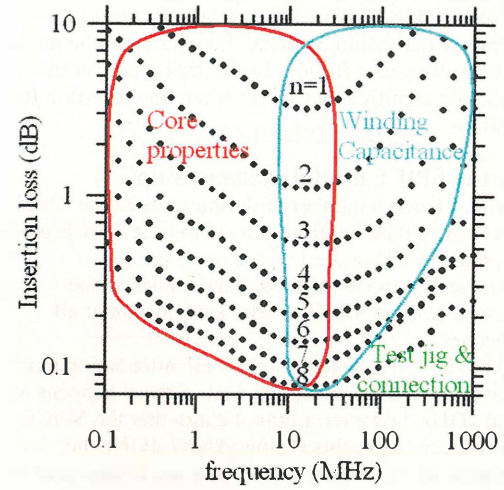


b: loss of a step-up transformer.

Fig.25. Insertion Loss spectrum of one transformer measured in back-to-back circuits of Fig 7. Black curves are measured values, red curves are simulations using the model in Fig. 24.



a: loss of a step-down transformer.



b: loss of a step-up transformer.

Fig.26. The parts of the model which control the Insertion Loss spectrum of the transformers.

Kramers-Kronig relations

Take a load with resistive and reactive components. Draw an arbitrary graph of the variation with frequency of the resistive component. Are you now free to draw another arbitrary graph for the reactive component?

If negative resistance is not allowed, and inductors increase in reactance as frequency increases, and capacitors do the reverse, it follows that the options for the graph of the reactive component are very limited. In fact, if the resistive component is known at all frequencies, it is possible to calculate the reactive component's variation with frequency exactly.

Similar logic constrains the frequency and phase response of passive filters. If it were possible to break the rules, it would be possible to see into the future; filters could give an output in response to an input that had not yet been applied. So resistive and reactive components of a load have to be related in a way that produces a time response that is possible.

Strictly, the Kramers-Kronig relations connect the real and imaginary components of the permittivity of a dielectric[11]. But, assuming a finite loss, relationships of the same form exist between the real and imaginary components of:

the permeability of a magnetic material
the impedance of a capacitor or inductor
any arbitrary impedance.

If an arbitrary impedance obeys the Kramers-Kronig relations, it also follows that it must be possible to construct an equivalent circuit using a network of passive components.

Fig 25 shows, in red, the curves that result from the model. I think they are a reasonable fit.

Wire Diameter Reviewed

The transformers discussed in this article were all wound with 8 turns of 36SWG wire. Threading the last few turns onto the core was always a struggle because the core was nearly full. This part has shown that I could have used much thinner wire for the n turns, but the m turns would have benefited from using much thicker diameter wire for the 8:1 and 8:2 turns ratio transformers.

It is when the output impedance falls to 3Ω or less that the 'brass tube' transformer comes into its own. The RF current flows on the inside of the brass tube, allowing the equivalent conductor diameter to be as great as the size of the hole in the ferrite. This greatly reduces the losses in low impedance windings.

By experimenting with the values of the component values of the model in Fig 24, it is possible to work out which part of the model dominates the various regions of the spectrum of insertion loss. The results of this exercise are shown in **Fig 26**. Clearly, there are further refinements that could be made. For example, the model makes no allowance for loss by RF radiation, yet this will probably be significant at 1GHz where the insertion loss is 0.2dB.

How the SPICE model measures up

In Part 1, I listed a number of deficiencies of the 'usual' model. It would be unfair not to submit the SPICE model to the same tests:

a) The unlike the usual model, the values of the components in the SPICE model are constant at all frequencies.

b) Above f_U, the SPICE model's HF attenuation has additional HF pass-bands. The first of these happens at around 2GHz, however, I do not claim that the SPICE model is accurate in this region. Above 1GHz the impedance of the connection wires plays a large part in determining the response.

c) This article has only dealt with the magnitude of the transmission response. This is a quarter of the whole picture: which should also include the phase response and the magnitude and phase response of the reflection response. Ideally, I would have done this work using an automatic network analyser, but a radio amateur budget does not stretch that far. However, from the limited tests I have done, the SPICE model's phase response represents a great improvement.

d) The SPICE model does not rely on L_L, the unpredictable leakage inductance. This is replaced by the predictable delay of transmission lines, and by the characteristic impedance of transmission lines, which we can at least make an informed guess.

e) The SPICE model works reasonably well for the prediction of transformer matching components, whereas the 'usual' model fails badly near f_U.

Conclusion

I have described a SPICE model for the small signal small size RF Transformer - I think it is a success, but then I'm bound to say that having spent five years of spare time researching it. However, it might be said that what I have done is measure a transformer using the traditional short and open circuit tests, and then build a model to fit the data, so of course it works. So the real test will be how useful the model is to circuit designers.

I hope the separate parts - the core material, skin effect and the transmission-line winding, prove useful on their own. And I hope that it makes designers think of RF transformers in a way that does not depend on leakage inductance or lumped elements. I also hope that manufacturers will feel prompted to characterise their materials over an adequate frequency range and to publish simulation models, preferably with tolerance values for the individual components. ■

Deriving the values in the skin and proximity effect models

To model the skin effect, I used the formulae given by Ramo et al[13]. The formulae are not simple, and are prone to calculation errors because they start at low frequency at 0/0 and finish I used as the input to the curve fitter in SigmaPlot (this was more convenient than Mathcad), together with a formula for determining the complex impedance of the ladder network. This gave values for R and L that gave a best fit to the data for each wire diameter in Fig 20. I admit that I adjusted the weightings for various parts of the graphs in order to give a good fit around the transition frequency where the skin effect becomes significant. Ref 15 gives a method for modelling the skin effect; this results in an equivalent, but different circuit.

I also used Dowell's approximations, again using Mathcad Pro to generate a table of R and X_L against frequency and the curve fitter to find the values shown in Fig 22. I gave Dowell's internal reactance curves very little weight in the curve fitter, because I suspect that they are in error. Look at Fig 21. In the skin effect curves, at high frequency X_L=R, but this is not true for the curves with proximity effect. I suspect that the latter break the Kramers-Kronig relations.

References

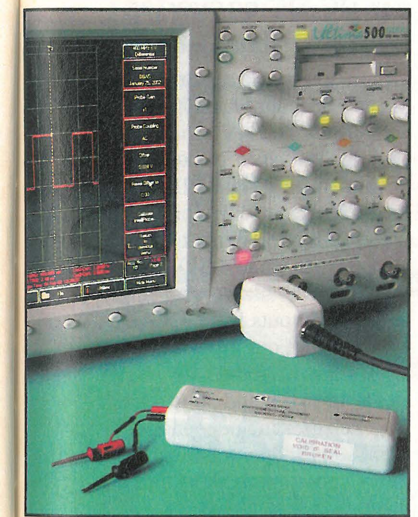
9. E.C. Snelling, and A.D. Giles: 'Ferrites for Inductors and Transformers', Research Studies Press, 1983, pp. 114-116
10. Nic Hamilton: 'A cheaper alternative to measuring complex impedance', RF Design, Jan. 1999, pp. 30-32
11. Simon Ramo, John R Whinnery, and Theodore Van Duzer: 'Fields and Waves in Communication Electronics' 3rd Ed, John Wiley & Sons Inc 1994, pp681-682 & pp563-564
12. Audrey M. Urling, Van A. Niemela, Glenn R. Skutt, and Thomas G. Wilson: 'Characterizing High Frequency Effects in Transformer Windings - A Guide to Several Significant Articles', IEEE 1989, pp. 373-385
13. Simon Ramo, John R. Whinnery, and Theodore Van Duzer: 'Fields and Waves in Communication Electronics' 3rd Ed, John Wiley & Sons Inc 1994, pp184-185
14. Reference Data for Engineers: Radio, Electronics, Computer, and Communications', (7th Edition) Ed. EC Jordan, Sams, 1985, Chapter 6 p13
15. S. Kim and D.P. Neikirk: 'Compact Equivalent Circuit Model for the Skin Effect', IEEE MTT-S International Microwave Symposium Vol. 3, June 17-21, 1996, pp1815-1818
16. P.L. Dowell: 'Effects of eddy currents in transformer windings', Proc. IEE, Vol. 113, No.8, August 1966, pp 1387-1394

NEWPRODUCTS

Please quote *Electronics World* when seeking further information

Scope probes for differential voltages

Gould Nicolet Technologies has introduced a range of measurement probes for its Ultima and Accura families of digital and transient storage oscilloscopes. The high impedance probes include differential voltage and current models and they integrate with the scope so that range, coupling and offset, including automatic zero offset calibration, can be controlled.from the instrument. Called the Intelliprobe range, it includes a 400MHz probe with up to ±40V of input signal offset. There are also 100MHz versions. All probes have a high common mode voltage rejection (±1400V) The current probe is specified up to 100A DC coupled and is a hall effect probe with a frequency range up to 100kHz. The Ultima 500 is a four channel scope with sampling speeds of 2Gsample/s. The Accura is a 100Msample/s sampling scope.



Gould Nicolet
Tel: +44(0) 20 8500 1000
www.gould-nicolet.com

Add-on board for AVR development

Atmel has announced the STK 594 add-on board that supports its AVR-based FPSLIC family which integrates a 20MIPS 8-bit AVR microcontroller with a 5,000 to 40,000 gate FPGA, up to 36 k-bytes of SRAM, and peripherals. FPSLIC devices provide programmable logic and an AVR microcontroller. The add-on board plugs directly into an AVR STK500 development board, creating a development environment. The HDL Planner tool in System designer automates the generation of the FPGA design, so embedded designers who are not familiar with hardware description language (HDL) can create the FPGA portion of the design.

Atmel
www.atmel.com

16-bit micro with LCD

Hitachi has introduced a 16-bit microcontroller with 4x40 segment integrated LCD, 256byte of embedded flash and 16kbyte RAM. The H8S/2268F is designed for applications such as gas, water and electricity metering. It is available in a 5V version running at 20MHz (50ns minimum instruction cycle) and in a 3V version running at 13MHz. The device's peripheral set includes a TPU timer unit featuring three channels of 16-bit timers with up to 8 input capture or output compare functions; three serial ports offering support for 12C and a subset of the smartcard standard ISO7816-3; a ten channel 10-bit resolution analogue/digital converter and a two channel 8-bit digital/analogue converter. The device also features the firm's pseudo DMA function Data Transfer Controller (DTC) and has low power support including a 32kHz subclock, which offers a power consumption of 4μA in watch mode. It is available in a 100-pin Quad Flat Pack package.

Hitachi
Tel: +44(0) 1628 585161
www.hitachi-eu.com

8051 micro makes 50% power saving

Philips Electronics has introduced a family of low power 8-bit microcontrollers for battery-powered devices. The 80C51X2 family of micro-controllers support both 6-clock and 12-clock operation, and performs over a operating range of 2.7V to 5.5V with up to 50 per cent less power consumption when compared to the original 12 clock 80C51 family.

Philips Electronics
Tel: +44(0) 3140272 2091
www.semiconductor.philips.com

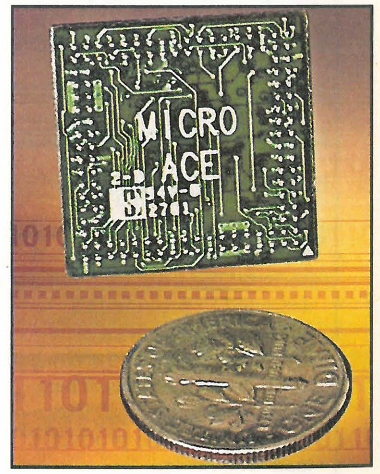
Board simplifies I/O layout

Dexdyne has introduced a P100 type processor single-board computer for embedded applications. Typical uses include instrumentation, data logging and telemetry equipment, vending machines, operator interfaces and information displays. Called Total-Control2, it has a footprint of around 145 x 100mm, which is similar to that of 3.5" hard disk drive. Power consumption is less than 4W at 100MHz, making it suitable for portable and other battery powered applications. Using the STPC/Atlas 586 processor running at 133MHz, the board will run Linux, DOS, or Windows CE type operating systems. The board runs from a single 5V power supply. The board is designed to be used as a controller and I/O includes five USB ports, four serial ports, IrDa, and 10/100 Ethernet. It will support VGA CRT and LCD displays up to 1280 x1024 resolution, it also includes a 4/8 wire touch-screen interface. Memory support includes IDE interface and compact flash; its four memory sites will accommodate up to 128Mbyte of surface mount SDRAM. The board's I/O design brings all I/O to one edge, using a secondary board that can be customised if required. Designed and manufactured in the UK, the controller board is in production. Evaluation systems start at £495.

Dexdyne
Tel: +44(0) 1285 658122
www.dexdyne.com

Mil-STD-1553 in BGA package

Data Device Corporation (DDC) has expanded its enhanced Mini-ACE MIL-STD-1553 component offering with the introduction of a ball grid array (BGA) package referred to as the Micro-ACE (μ-ACE). This is



claimed to be one of the first MIL-STD-1553 components available in a BGA package. 1553 is the standard two-wire databus system used by military aircraft as well as in defence and space equipment.

Data device Corporation
www.ddc-web.com

Please quote *Electronics World* when seeking further information

Big shrink for chip capacitors

Murata has reduced the dimensions of two of its high voltage ceramic chip capacitors. The X1/Y1 and X1/Y2 class devices in disc packages are up to 20 and 15 per cent smaller than their respective predecessors, said the supplier. The KX(X1/Y1) range is rated at 250V AC and offers capacitance from 100pF to 4700pF in disc packages with vertical leads and diameters ranging from 8 to 15mm. They are intended for applications in AC line filter and power coupling. The KY (X1/Y2) devices range in capacitance from 10pF to 4700pF in disc packages of diameters from 7 to 10mm. The lead spacing is 5mm, which is suitable for automatic insertion. Both ranges hold IEC384-14 UL1414 approvals. Operating temperature range is –25 to 85°C.

Murata
Tel: +44(0) 1252 811666
www.murata.com

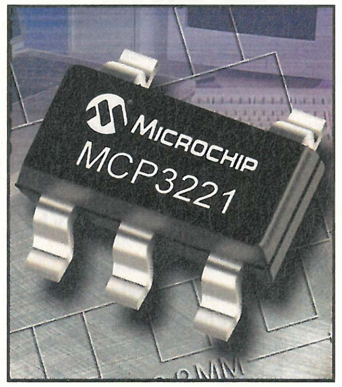
Differential amplifier for high speed ADCs

Analog Devices is targeting its latest fully differential low noise amplifier at applications replacing op amps in some high speed analogue-to-digital conversion (ADC) circuits. The AD8351 device is designed to drive 12- to 14-bit ADCs at 70MHz. The ampilfier's –3dB bandwidth is 2.2GHz with a gain of 12dB which means it will also support 10-bit distortion performance at 240MHz. Slew rate is 11.00V/µs. Based on the firm's eXtra Fast Complementary Biplolar (XFCB) and Silicon on Insulator (SOI) manufacturing processes, the device draws 135mW at full bandwidth. The amplifier has a noise spectral density of $2.2nV/\sqrt{Hz}$ and 2nd/3rd order harmonic distortion of –79/-81 dBc at 70MHz. Target applications are expected to be in 3G telecoms infrastructure and test systems. The AD8351 is currently sampling and available in a compact 10-pin microSOIC package.

Analog Devices
Tel: +44(0) 1932 266000
www.analog.com

12-bit ADC comes in SOT-23 for neatness

Microchip's latest 12-bit analogue-to-digital converter (ADC) with an 12C interface is available in a SOT-23 package. The MCP3221 is a successive approximation 12-bit ADC with



a 2-wire serial interface which enables sampling rates up to 22.3ksample/s for high bandwidth signals. Active power consumption is 175µA with a typical standby current of 5nA. It can operate from a single 2.7V to 5.5V supply and there is sample and hold circuitry on-chip. The design also makes it possible to have a single 12C bus while addressing up to eight different devices. The device is specified for a standard industrial temperature range (–4 to 85°C).

Microchip
Tel: +44(0) 118 9215858
www.microchip.com

6W DC-DC converter on the surface

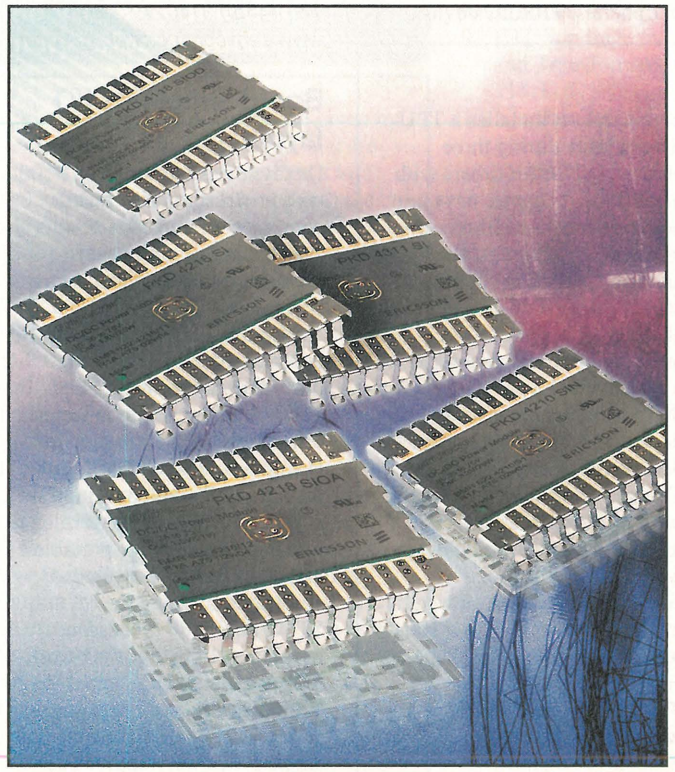
Power-one has added to its range of surface-mountable DC-DC converters. The NV series provides up to 6W of output power from a 24-pin DIL surface mount package with a profile of 8.5mm. Providing input-to-output isolation of 1.5kV DC, models are available with single and dual outputs from 3.3V DC to 24V DC. Four input voltage ranges are available: 9 to 36, 18 to 36, 18 to 75, and 36 to 75V DC. Features include magnetic feedback for operation up to 110°C, continuous short-circuit protection, input-transient protection, and lead coplanarity within 0.1mm.

Power One
Tel: +44(0) 1425 474752
www.power-one.com

Lead-free DC-DC with 1.2V/14A output

Ericsson Power Modules has expanded its PKD series of single-output, lead-free DC-DC power modules to include versions with 1.2V/14A, 1.5V/14A, 1.8V/14A, 2.5V/12A and 5V/6A outputs. All use a 48V input. The module dimensions are a height of 7.5m on a footprint of 46 x 50mm.
With efficiency specified at 88 to 90 per cent, they are designed to provide full power in ambient temperatures up to 70°C when force cooled at 1m/s. The supplier attaches specific importance to the product's lead-free design. Its input/output isolation is 1500V DC and typical mean time between failures (MTBF) is over 590 years at 75°C.

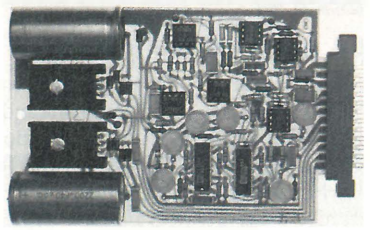
Ericsson
Tel: +44(0) 046 8568 69620
www.ericsson.com

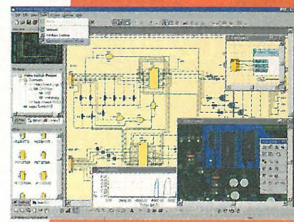


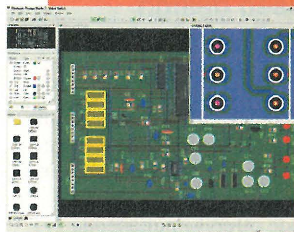
Power switch replaces transformers

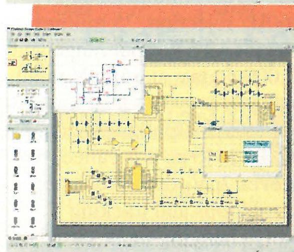
Power Integrations has introduced a switching power supply IC that is designed to replace linear transformers in adapters and battery chargers rated at 3W and below.
The linkSwitch LNK501 enables a fault protected, universal input (85V AC to 265V AC), constant voltage constant current (CV/CC) output switching power that meets worldwide energy efficiency standards. The device is available in both through-hole and surface mount DIP packages.

Power Integrations
Tel: 408 414 9200
www.powerint.com









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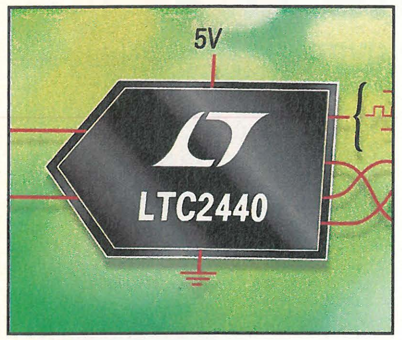


24-bit ADC has variable speed design

Linear Technology has introduced a 24-bit ADC incorporating the firm's 'No Latency Delta Sigma' variable speed/resolution architecture - which offers 10 speed/resolution modes. A 6.9Hz output rate mode offers simultaneous 50/60Hz rejection, 25 million counts at ±2.5V input range and 500,000 counts at ±50mV input range.

The 880Hz output rate mode, of the LTC2440 as it is called, achieves $2\mu V_{RMS}$ noise for control loops and tracking rapidly changing input signals. Maximum output rate is 3.5kHz and all speed/resolution modes are selectable through a serial interface.

Transparent auto calibration is said to make output codes independent of time, temperature, supply and speed selection.

The digital filter always settles in one conversion cycle even if there is a change in speed/resolution or a change in an external multiplexer input channel.

Absolute accuracy (5ppm INL, 1ppm offset, 10ppm full-scale) is independent of changes in the output rate. The LTC2440 comes in a 16-pin SSOP package in industrial and commercial temperature ranges.

Linear Technology
Tel: +44(0) 1276 677676
www.linear-tech.com

100A circuit breaker has status

E-T-A is offering 100A circuit-breaker-for-equipment (CBE) with an auxiliary contact to provide status information. This is a modified version of its existing standard E-T-A 452 which is used in aircraft flight decks, telecommunications and process control, said the company. The firm's new version, with status contact, is a combined push/pull switch and circuit breaker with a thermal-magnetic tripping mechanism for thread-neck panel mounting in low voltage applications and is available in a range of current protection values from 50A to 100A. Inside a solenoid provides rapid cut-off in the event of short-pulse high-current overloads, and the bi-metal thermal cut-out, in series with this solenoid, responds to prolonged low value over-loads.

E-T-A
Tel: +44(0) 1296 420336
www.e-t-a.co.uk

Toroidal inductors have MPP core

Standex Electronics is making its surface mount toroidal inductors available with a molypermalloy powder (MPP) core. The original ST2006 and ST2207 cores used a ferrite. New SP2006 and SP22007 families come with values up to 330µH.

The use of MPP extends temperature range from 85ºC to 155ºC, gives better saturation characteristics, and is better suited to frequencies up to 500kHz where the current is mainly DC. The most common applications for the SP and ST Series inductors are DC-DC power converters for portable electronic devices. This is generally any battery-operated handheld portable electronic device containing a power supply for which space and weight is at a premium.

Standex Electronics
Tel: +44(0) 1513 871377
www.standexelectronics.com

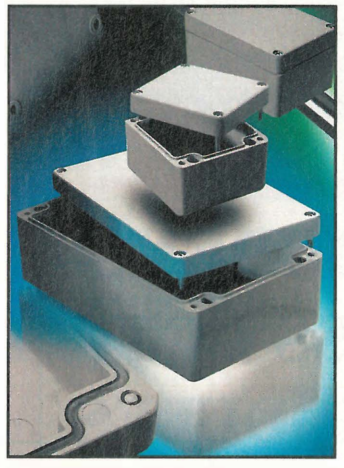
IP65 sealed enclosures are glass reinforced

Hammond Electronics has introduced a family of IP65 sealed heavy duty watertight glass reinforced polyester enclosures. Suitable for the electrical, electronic, process and other industries where a rugged, corrosion and shock resistant housing is required, the1590ZGRP family provides a lightwave alternative to die-cast aluminium enclosures. The seven units in the family range in size from 80 x 75 x 55mm to 260 x 160 x 90mm.

All sizes feature an internal mounting shelf and captive mounting nuts moulded into the base section; the lid is secured with four captive screws located outside the gasketed tongue and grove seal and the unit can be mounted to a surface through box blind holes, again outside the gasket protection.

The thick wall design provides good impact resistance and allows components to be securely screwed directly into the body of the enclosure without compromising the IP65 sealing.

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

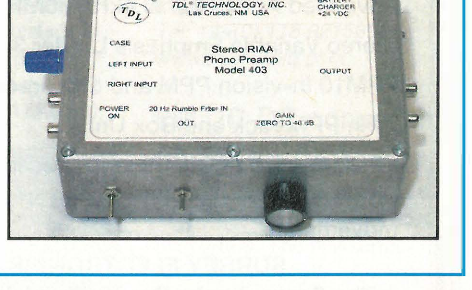


Stereo RIAA phono preamp

TDL Technology announces their Model 403, Stereo RIAA phono preamp designed to drive a sound card's line-input for restoring vinyl LP records which were recorded using RIAA equalization. The preamp uses low-noise opamps and features low output noise and low power line hum pickup. When used with a high-quality direct drive turntable, this preamp will readily produce CD-quality wave files with little software editing. The internal rechargeable batteries provide complete isolation from the power mains and the cast aluminium enclosure minimises the pickup of unwanted interference.

A full data sheet and user guide in PDF format can be downloaded from their web site.

TDL Technology
Tel: 505 382 8810



Schottky diodes are this small

Rohm Electronics has expanded its range of Schottky diodes with seven surface mount devices that are designed for small size. The diodes feature forward voltage ratings down to 0.28V (at a forward current of 1mA) and reverse current ratings as low as 0.5µA. All devices are supplied in small mould type packages with footprints ranging from 2.0 x 1.25mm down to 1.2 x 0.8mm. Average rectified forward current (Io) for the RB480Y and RB481Y is rated at 100mA, while all the other devices offer an Io of 30mA. At 0.28V, the RB481Y diode has the lowest forward voltage characteristic of the new range, while the

Please quote *Electronics World* when seeking further information

RB751S-40 and RB751V-40 have the lowest reverse current ratings at 0.5µA. The forward voltage of the RB480Y is specified as 0.38V, with the RB715F, RB715W RB731XN and both the RB751S-40 and RB751V-40 all having forward voltage ratings of 0.37V. Reverse currents are specified as 1.0µA for the RB480Y, RB715F, RB715W and RB731XN. Maximum reverse voltages are 30V or 40V depending on the device chosen.

Rohm
Tel: +44(0) 1908 282666
www.rohm.co.uk

Ceramic filters with low insertion loss

Link Microtek has a range of microwave dielectric filters and duplexers featuring maximum insertion loss figures in the region of 1.1dB. manufactured by Japanese firm UBE Electronics, the filters in the UF series include both surface-mount and dielectric devices. Typical maximum VSWR is 2.0 and signal attenuation ranges up to 55dB.

Microtek
Tel: +44(0) 1256 355771
www.microtek.co.uk

Edge connector provides backplane short-cut

The HSHM series of high speed backplane connectors from 3M is designed to offer signal shielding when the connectors are used at right-angles to each other so maintaining isolation between differential pairs. As a result, said the supplier, connectors on on opposite sides can be arranged in row and column formation respectively. This means that telecoms switching and line cards can be fitted to each side of the card so that each switching card can interface directly with each line card.

According to the supplier, this can have signal speed and integrity benefits over current designs where the switching and line cards each have to be connected to a backplane. As a result cards can be positioned back-to-back through the mid-plane at a 2mm spacing. Also by positioning differential pairs in rows instead of columns the signal skew that can arise from backplane interconnectors can be reduced and even eliminated, said the supplier.

3M
Tel: +44(0) 1344 858000
www.sendmeone.info/3mhs

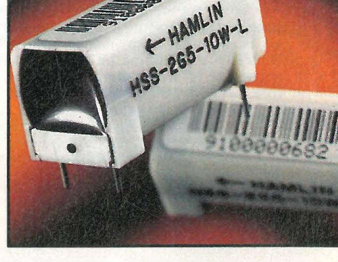
PCB connector for video cards

Hirose's DXLM range of connectors conform to all the requirements of the RC-5237 EIAJ standard for digital image broadcasting. The PCB-mount connector is available with 14 gold plated contacts, in straight or right-angle through hole versions, that are all capable of mounting on a panel up to 3mm thick. The outer shell of this connector will always ground before signal contacts, protecting equipment against the effects of electrostatic discharge. The metal grounding posts also double up as PCB retention points for additional strength. The plugs are supplied assembled to the EIAJ configuration in 1.5 or 3 metre lengths, and feature side latches that give an audible click when fully mated.

Hirose
Tel: +44(0) 1908 305400
www.hirose.com

Shock sensor for safety critical balancing

Hamlin Electronics is launching a range of shock sensors available in four different sensitivity options, 2G, 2.5, 5 and 10, and can now be used for applications such as low sensitivity detection, to sense overloading or 'off balance' and in security applications to sense if a product or package has been moved or dropped. The shock sensor is particularly suited to 'safety critical' applications, said the supplier.



Hamlin Electronics
Tel: +44(0) 1379 649700

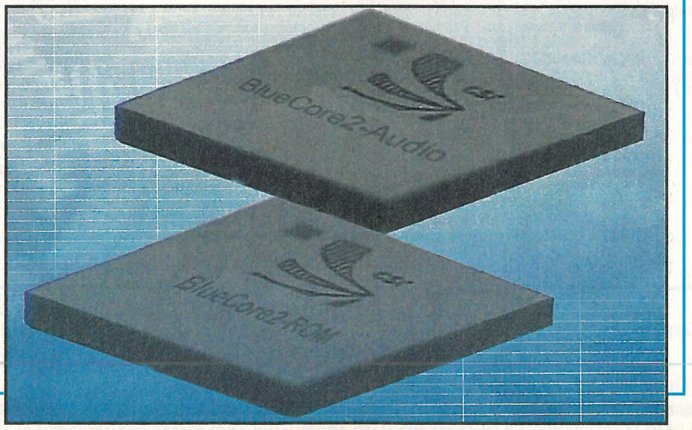
Bluetooth with memory

Cambridge Silicon Radio (CSR) has launched two chips in its BlueCore2 family of Bluetooth devices aimed at low cost, high-volume applications. BlueCore2-ROM and BlueCore2-Audio are CSR's first Bluetooth devices which do not need external non-volatile memory.

The ROM version is aimed at the mobile handset market, while the Audio chip is geared more towards headsets. The latter integrates a 15-bit audio codec, microphone amplifier and speaker drivers.

Component count is further reduced as both devices integrate loop filter components and a linear voltage regulator. The overall footprint for a complete Bluetooth system can be as little as 64mm², the firmed claimed, using the 6x6mm ball grid array chips. BlueCore2-ROM and BlueCore2-Audio are now fully qualified between –40 and 105°C with samples available. They will be shipping in volume from Q4 2002.

Cambridge Silicon Radio
Tel: +44(0) 1223 692000
www.csr.com



400Mbit/s serial interface controller

Epson has developed a link controller for the high speed serial interface standard IEEE 1394a-2000 used in multimedia networking applications, which allows data transfer of up to 400Mbit/s.

The SIR72805 incorporates a link control function that realises the IEEE 1394 interface using PHY together with USB 1.1 control function, and bridges between an IDE interface.

Typical application fields are PCs and PC peripherals that have IEEE 1394 and/or USB 1.1 interface.

Epson
Tel: +44(0) 49 89140 05419
www.epson-electronics.de

CIRCUITIDEAS

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

The best circuit ideas are ones that save time or money, or stimulate the thought process. This includes the odd solution looking for a problem – provided it has a degree of ingenuity. Your submissions are judged mainly on their originality and usefulness. Interesting modifications to existing circuits are strong contenders too – provided that you clearly acknowledge the circuit you have modified. Never send us anything that you believe has been published before though.

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

Clear hand-written notes on paper are a minimum requirement: disks with separate drawing and text files in a popular form are best – but please label the disk clearly. Where software or files are available from us, please email Jackie Lowe with the circuit idea name as the subject.

Send your ideas to: Jackie Lowe, Highbury Business Communications, Anne Boleyn House, 9-13 Ewell Road, Cheam, Surrey SM3 8BZ email j.lowe@highburybiz.com

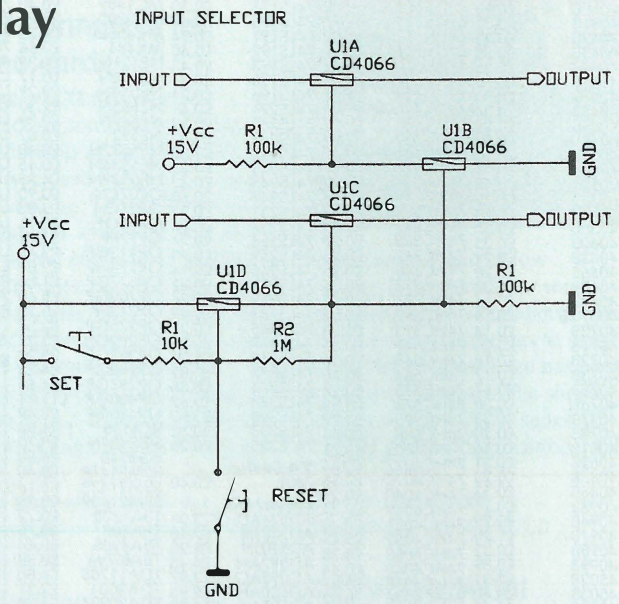
Solid state latching relay

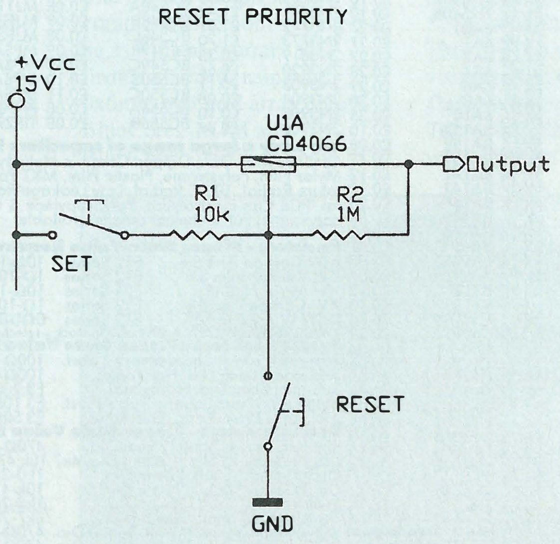
It is easy to emulate a basic latching relay circuit using a single solid-state switch. What needs to be done is create a feedback loop to maintain the selected state. As with the latching relay circuit there are two possible configurations.

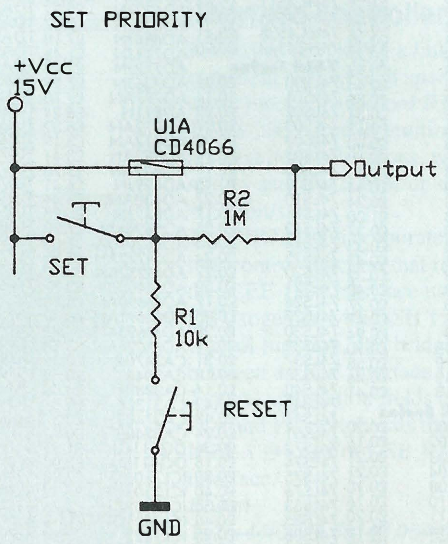
The first circuit is a circuit with set priority. The resistor in series with the reset button disables it when the set button is depressed. Placing the resistor in series with the set button creates a circuit with reset priority.

As there are four solid-state switches in each package it is possible to create a selector with the remainder as shown in the third circuit. Here a switch is used as an inverter.

Bernard Van den Abeele
Evergem, Belgium

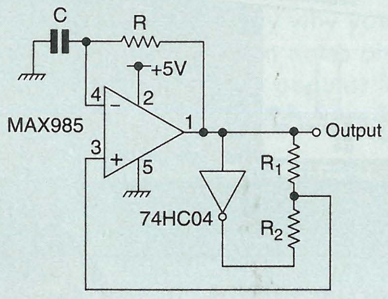






Relaxation oscillator

Unlike the common relaxation oscillator, this alternative doesn't suffer from variation in the potential to which the capacitor is charged.



As compared to the well-known oscillator circuit using one op-amp, the circuit as shown here eliminates the variation in potential to which the capacitor *C* is charged.

The 74HC04 ensures that the two arms of the differential output stage cannot remain in the same logic state and that the only time that they are equal in voltage is when traversing the logic uncertainty levels.

This property permits a threshold setting circuit that varies in accordance with the charging voltage applied to the tuning capacitor, thus automatically compensating for any change in charging potential – the advantage of this new circuit.

A rather tedious computation shows that a ratio of R_1/R_2=2.5 improves the symmetry error.

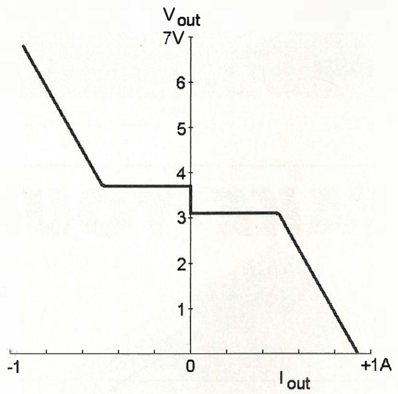
Kaimil Kraus
Rokycany
Czech Republic

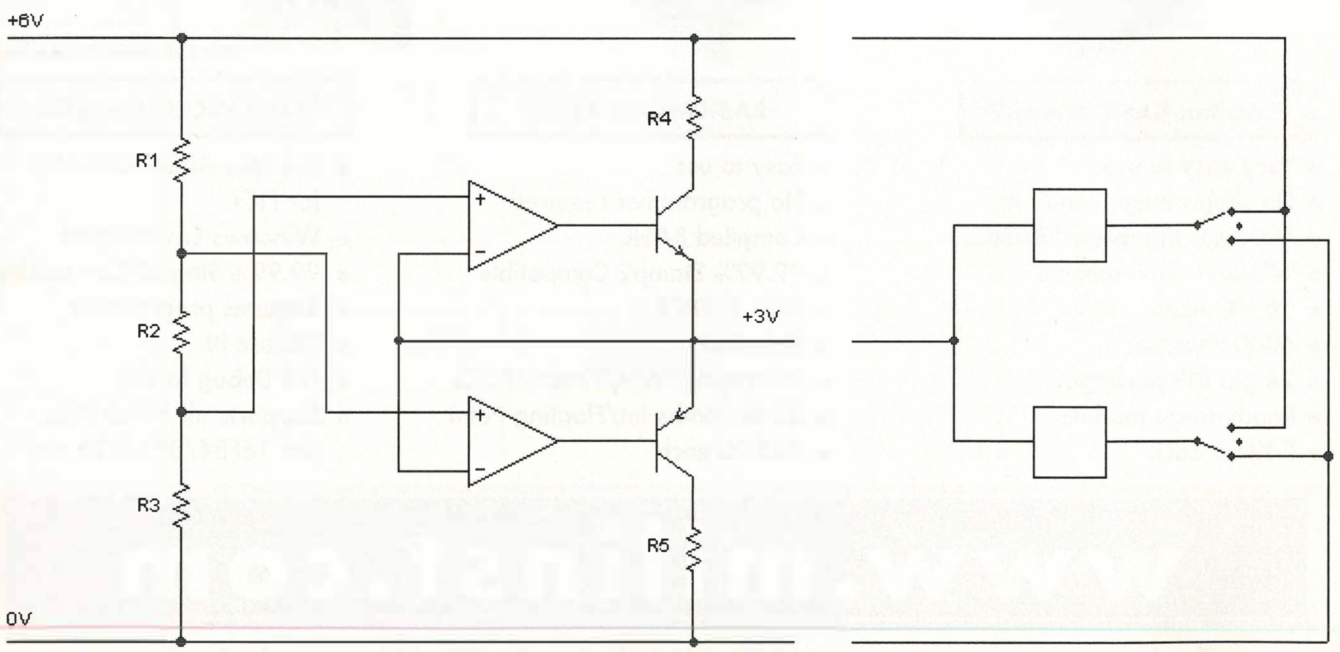
Rail Splitter with Dead Band

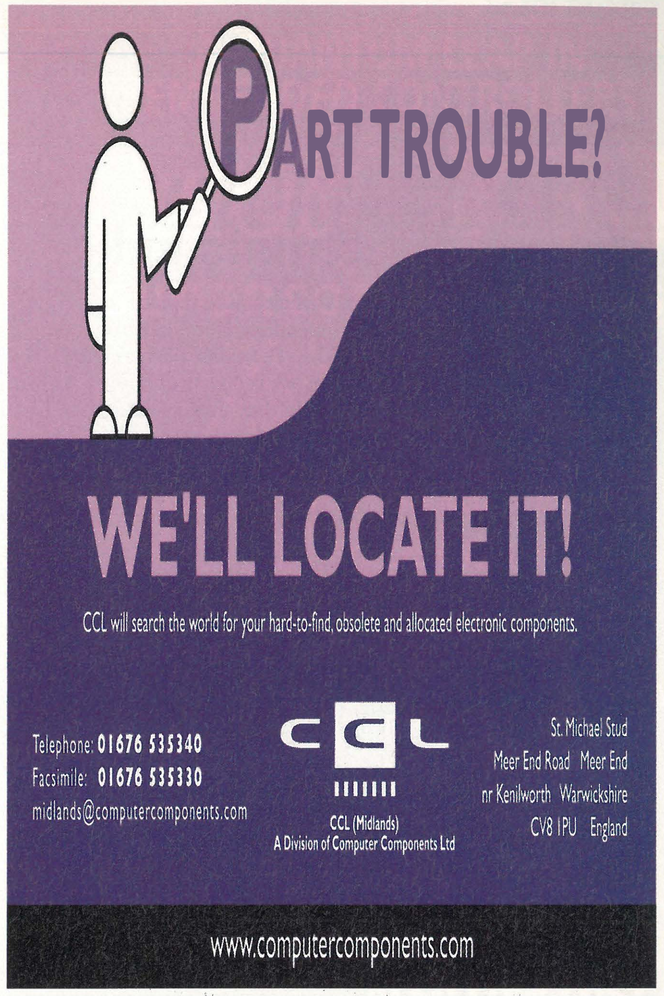
This circuit was developed for a 6V gel-cell/solar-powered device. The electromechanical loads shown on the right are normally connected in series across the rails, half-bridge drivers being drawn as switches for simplicity. (Other details of the load such as filter capacitors and clamp diodes are not shown.) Most of the time, the nature of the mechanical load takes care of load-sharing if left to its own devices. The half-rail point typically stays within 250mV or so of nominal, this circuitry drawing minimal current.

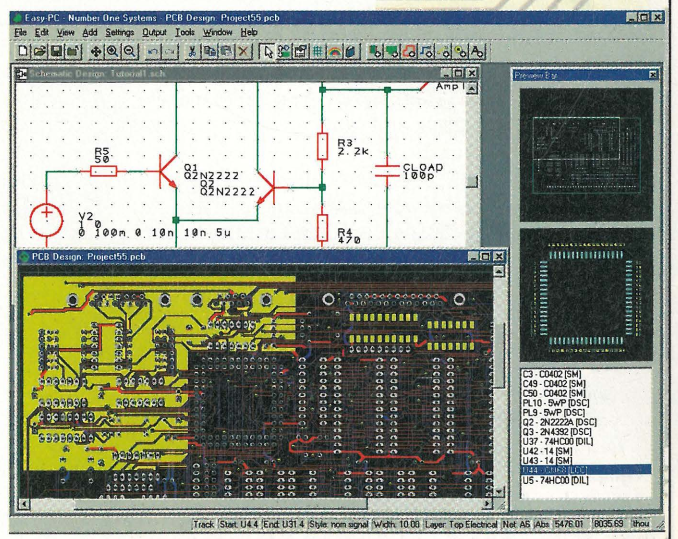
(Even in Australia, solar-powered devices should be energy-efficient!) When one or both loads are reversed or stalled, there is a momentary need for the splitter to source or sink a few hundred mA. Resistors R1, R2, R3 set the dead band; R4 and R5, in conjunction with the CMOS op-amps' current limiting, provide short-circuit protection. The graph shows typical output V-I characteristics for R1 = R3 = 33k, R2 = 6k2, R4 = R5 = 6R8.

Peter Horn
Katoomba, Australia









Electronic indicator for motorbikes

I designed this circuit to replace the old electro-mechanical indicator on my motorbike. These old flashers are designed to work properly only on a certain load and they give problems when one lamp bums out.

Instead, the circuit shown in works perfectly for currents down to 10mA – though I doubt that you'll be able to find 5mA lamps. It is based on the clever 'series' topology described in reference, where C_2 is used both as a timing element and as a voltage source for high-side driving.

The availability of the high-side voltage led me to the use a power MOSFET as the output element, Tr_2. This choice improves duty-cycle symmetry, as the capacitor charges through R_4, but discharges on $R_4//R_3//R_2//R_1$. Also, resistor R3 can be much larger than would otherwise be the= case.

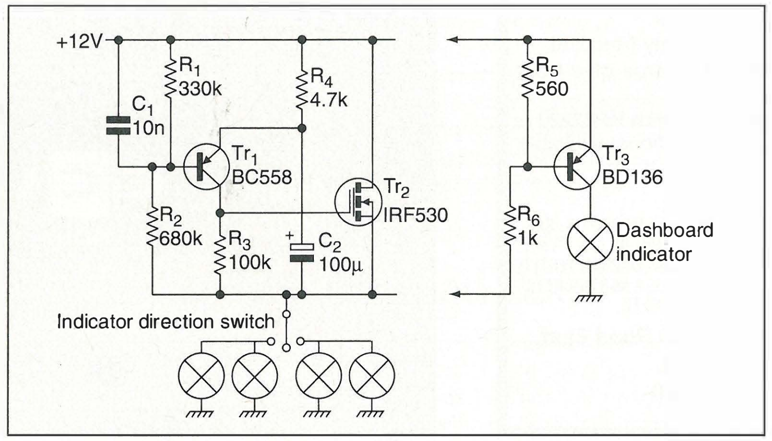
Note that symmetry can be impaired by the fact that the turn-on threshold is determined by R_1, and R_2, while turn off is set by the $V_{g(on)}$ of Tr_2.

Neglecting $R_3//R_2//R_1$, timing is set to around 1.5Hz by R_4 and C_2. Capacitor C_1 insures clean turn-off of the circuit.

The subcircuit on the right can be added to provide the 'third wire' to drive a dashboard indicator if you need one.

Paolo Palazzi
Cervignano
Italy

A motorbike's electromechanical indicator system is fine but it doesn't work properly if a lamp fails – unlike this circuit, which remains functional at currents down to 10mA.



Reference

1. B Van den Abeele, 'Versatile flasher circuit', *Electronics World*, April 2001, p. 299.

Audio activated switch

£50 winner

If an audio input is sensed that's greater-than 200mV pk-pk for about 60ms, this circuit can cleanly switch mains to remote amplifiers. Ideally, the device carrying out the switching will be a solid-state relay, which isn't shown. A simple four-pin, 4A device is available from Farnell, catalogue No 722-9082, at about £9. Alternatively, you could make a relay up using an opto-isolator, triac etc.

Sensitivity quoted above applies between 500Hz and 2500Hz. At 50Hz it is 500mV while at 10kHz and 20kHz, 400mV and 700mV are required respectively.

Using a permanent ±15V supply, current drain is about 4mA, making power required just an eighth of a watt.

When input at Tr_1 is greater than 200mV, a comparator triggers to a saturated output. After rectification, this signal charges up C_3 in about 60ms. The second op-amp acts as a fast trigger to switch the output high. An emitter follower provides a +5V signal drive the mains-switching relay.

The time constant of C_3/R_{10} causes discharge after five minutes or so to cleanly switch off the trigger.

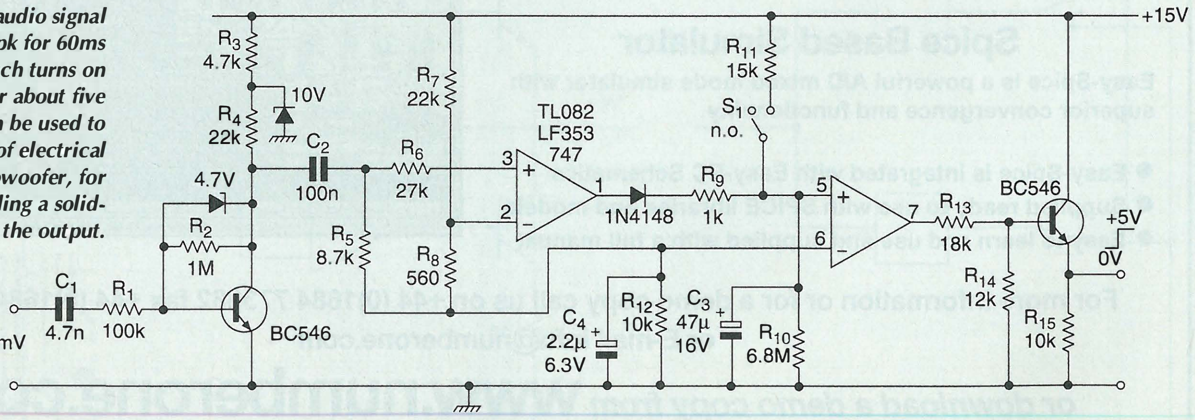
Switch S_1 is provided to permanently switch the output on, should that ever be required.

The 60ms requirement prevents mains spikes from causing false triggering. Such spikes don't have enough energy to charge up C_3.

Note that I don't claim complete originality for this design. It is rather a collection of ideas from others that I have brought together for a particular application.

Paul Nelson
Congleton
Cheshire

On receiving an audio signal above 200mV pk-pk for 60ms or so, this switch turns on and stays on for about five minutes. It can be used to turn on a piece of electrical equipment – a subwoofer, for example – by adding a solid-state relay at the output.



LETTERS
to the editor

Letters to "Electronics World" Highbury Business Communications, Anne Boleyn House, 9-13 Ewell Road, Cheam Road, Surrey SM3 8BZ e-mail j.lowe@highburybiz.com using subject heading 'Letters'.

Cyril on measurements

While I applaud the attempts to use low cost measurements whenever they are adequate for the task in hand, I fear this is not so with the R. Black attempts to measure speaker cable distortions.

Before attempting any serious distortion measurements, especially those planned for publication, one should first attempt to quantify the level of distortion that might be expected. Then add a safety margin. Typically 10dB as an absolute minimum should be provided.

In like fashion any signal source used must also be of lesser distortion, since any attempt to quantify small distortion differences, swamped by much larger distortions, is unrealistic.

Researching back publications, in measurements reported by G. Millard of BBC engineering, carbon-film resistors typically exhibit THD of around -120dB to -130dB, mostly third harmonic and intermodulation around -100 to -120dB.

Using my equipment, I too have measured similar values with carbon film, but even with a dynamic range of -140dB, cannot satisfactorily measure differences in metal film resistors. For that much lower distortion equipment, or a different measurement, is required.

Surely one must assume that all copper based cables will produce less third harmonic distortion than the best resistor? I can find no statement as to exactly which soundcard or even test voltages he used. Most modern cards are 16 bit only but a select few are 20 bit or better. Dynamic range of an unaided 16 bit card is not sufficient, which is why I had to spend time and money developing a notch filter/preamplifier.

For my initial experiments, in August 2001, I did try using my Soundblaster 1024 Live card with the signal generators in 'Cool Edit', to measure capacitors. These signals are far from distortion free and all attempts failed. Noise and distortion from the generator far exceeded and clouded those I was attempting to measure. I also tried measuring intermodulation distortion differences, using these signals. To say the results I found were utterly confusing would be an understatement.

From my experiences I suspect that Black's attempts to measure cable distortions using his system were doomed to failure from the beginning. Perhaps he also was making the wrong measurements. Even using the much vaunted AP test set would not, I believe, be sufficient to measure distortions in speaker cables.

Failure to measure differences using a test method may prove comforting, but it does not prove that cable distortions or differences will not be found in more realistic tests.

To paraphrase a sentence from my first 'Capacitor Sounds' article "truly audible differences must be both understandable and measurable. Understanding in terms of construction. Measurements may however require a change in measurement technique."

From my earlier work on speaker cables I know that audible distortion differences certainly do occur with change in cable construction. Measuring them is quite another matter.

Cyril Bateman
Acle, Norfolk, UK

Nonsense required

Congratulations! you've certainly found a way to generate a decent mailbag.

So here's my addition to the heap. Like many readers, I still remember and even think of the magazine as 'Wireless World'. I always preferred EW in its various incarnations to the other 'hobby' magazines, because the latter seemed aimed more towards readers who wanted to build things, without necessarily really understanding what they were doing, or (worse) how to fix their creations when they didn't work properly. Trouble is, they gave me the job. Personally, I generally prefer to build things I design myself.

I have very much enjoyed the off-the-wall articles explaining how conventional e-m theory is fundamentally wrong. Ivor Catt's nonsense about transmission line theory, the 'ball bearing motors' article, the one about faster-than-light transmission of e-m pulses, and lately Dom di Mario's one about Faraday machines - a good old perpetual motion machine if ever there was one - all spring to mind. Yes, I know, they are rot, but hilarious rot, and the interesting thing is to puzzle out why they are rot. Doing so deepens understanding. Really. Rot deepens understanding. I think I'll designate that one 'personal thought of the week'.

But I am only one reader, and that is only one comment about content, a plea to keep on including something. I won't include requests not to include anything, because other readers may well want just that. There have been quite a few comments about what EW should not contain, but few of us mind skipping uninteresting articles provided there are enough interesting ones to read instead. Electronics is such a large field it seems quite impossible to make all articles interesting to all readers.

The general view that WW/EWW/EW rather lost its way between the early 1970s and now is one I generally agree with, sadly. What makes people lose interest in a magazine is finding little or nothing of interest in it. It seems to me there is only one way to avoid this, and hopefully to regain some of EW's former glory. It must include a wide range of types of articles covering a wide range of topics within the general scope of 'electronics'. This does mean that the spine really ought to be a bit thicker than at present, so readers with very diverse interests can nearly always find enough to keep them buying it.

Alan Robinson,
York, UK.

Look forward to a bit of 'nonsense' next month – Ed.

More nonsense

I first became a regular reader of Wireless World about 1955 and the articles that persuaded me to part with hard earned cash in those days and persuaded me to become a lifelong reader were the excellent debates on the theory of relativity and alternative theories that seemed to abound in those days. I well recall an article by P. Pappas and another entitled 'Faster than Light' drawing about a dozen letters all with a different theory. I felt sorry for Ivor Catt who seemed to get a lot of personal abuse when the perpetrator could not dismiss his theories. I suggest this is the stuff a good journal is made of. One that is not afraid to publish alternative views. Another attraction was the excellent and affordable state of the art projects for home construction and where would we be without 'Circuit Ideas? May I suggest you encourage alternative physics theories, encourage more projects for the home constructor especially with popular microcontrollers such as the Microchip PIC family, which are inexpensive and easily programmed.

Gareth Jones
Shrewsbury,
Shropshire, UK

Low distortion measuring – not so new

Mr. Bateman's articles are very good and many of the results are not available elsewhere. Similar work was done around 50 years ago on components for telephone carrier multiplex systems, where intermodulation distortion had to be reduced to very low values indeed. In those days, synchronous detection, using heavily damped mirror galvanometers as the bandwidth-defining filters, was used. I seem to remember that measurements were made down to -145 dB(V). Maybe somebody from the telecoms business in that era could give more details. I suppose the measuring signal was passed through passive filters to reduce its distortion to even lower levels. But there is a significant point that needs to be made about the applied a.c. voltage in Mr. Bateman's tests. In most applications where a capacitor is used in the signal chain (i.e. where its non-linearity, even of very low proportions, might matter) there is very little signal voltage across it. The whole point of a coupling capacitor is to transfer the signal without loss, i.e. there is next to no voltage drop across its impedance. The whole point of a decoupling capacitor is to hold the a.c. voltage (signal and/or power-supply stuff) across it to a very low value. So measurements, such as that shown in Figure 2, with 2V across the capacitor, are not realistic for most applications. However, in filter circuits, including tone controls, the impedances of the capacitors are NOT negligible - that's how the circuits give different frequency responses - and there can be large signal voltages across them. In some filter circuits, these voltages can be much larger than either the input or output voltage at some frequencies. Barrier-layer capacitors, which I suspect Mr. Bateman may have to bear some responsibility for, during his previous career (just a joke!), and which is what the text under 'The worst capacitor' refers to, without making that very clear, are normally identifiable through their low rated voltage, 6V or 12V usually. They are definitely to be avoided unless there is really no alternative. I am surprised that they are still made.

John Woodgate
UK

Budget T&M

I found this series of articles from Richard Black very informative regarding the measurements that can now be done with a PC & soundcard.

However, I think the choice of cables for comparison could have been better. Richard describes Supra Ply 3.4 as a low capacitance/high inductance cable, which is the direct opposite of what Jenvings, claims for this cable. My own measurements on the smaller version, Supra Ply 2.0, show it to be a low inductance cable with relatively uniform impedance up to 20KHz. I am not familiar with Goertz M1, but I suspect Richard has compared two cables of similar properties. Certainly he could have picked cables with more contrasting impedance properties. Including a cable with widely spaced conductors such as DNM's Reson cable would have made his measurements more interesting.

I think Richard has also discounted the influence of cable impedance on both frequency response and drive unit damping. Jenving data shows several dBs difference at 20KHz between cables and I have measured similar differences.

Colin Yallop
Derby, UK

Very earthy

Thank you for publishing my letter (EW August 2002). Ian Darney has not justified his view and you seem keen for mail on the issue, so here is my reply to Ian's article.

Ian's Fig. 1 "Concept of start point grounding" is a good example of how to incorrectly wire parts of a circuit.

The problem is not caused by the star point earth, but the way the wiring has been routed. If interference is likely to be a problem then the conductors (signal and return) need to enclose as little area as possible. The cure is very simple: twist the signal wires together with their respective earth wires. This technique is often used in domestic electronic equipment. Other techniques include using shielded cable and by using pc boards with a ground plane. By reducing the area enclosed by the signal and return conductors, the amount of field coupling the circuits (i.e. by "transformer action" as Ian describes it) is reduced.

Not only does this reduce interference but it has the added bonus of getting the signal from one point to another with less degradation, i.e. in the complete absence of interference this is a superior (and recommended) approach. This has little or nothing to do with the grounding topology, but it is another useful 'tip' for good EMC. Surprisingly, this approach will reduce capacitively coupled interference as well, although the mechanism is different. By placing the signal and return conductors closer together the wiring capacitance increases, but the capacitance to any interfering source is unlikely to change. This looks like a capacitive divider from the interference source, so as the cable capacitance (which is the shunt arm in the divider) increases the induced voltage is reduced. This extra capacitance is rarely a problem that cannot be easily overcome.

Ian's model has an unnecessary earth loop, which (as he demonstrates) introduces extra conducted interference. There is no sensible reason for the two circuits in Ian's model to be connected to the 'structure' at two places, one each is sufficient. Furthermore, there is nothing intrinsic to Ian's alternative that will reduce coupled interference (if anything it's likely generate more), so there is no reason for that to change and certainly Ian provides no explanation of how it might.

There is not a simple single solution to all interference problems. Earth loops are not always bad, but in my experience they often are. Conversely, good lead dress (e.g. twisting the wires, and routing wiring away from sources of interference such as power transformers) and a star or branching ground system (i.e. without loops) are good design tips. Simply connecting all grounds to one point and using the shortest possible wire to join the required nodes is bad practice, however the real villain is not the star point earth but the large areas enclosed by the signal and return loops (which is not inherent to star point earths).

Ian has not demonstrated that the star point ground system is intrinsically bad. In fact Ian has failed to identify the real problem, failed to address that problem, and unnecessarily introduced an extra problem. It may well generate some mail, but it hasn't advanced the subject.

Phil Denniss
Darlington, NSW Australia

Shaky Ground

Ian Johnson mounts a stout defence of the 'star-point ground' in his letter 'EMC'. (EW Sep 02). He takes exception to the opening paragraphs of an article 'Designing for EMC'. (EW Aug. 02).

The 'star-point ground' can be defined as a point to which all return conductors are routed and to which all system voltages are referred. At printed circuit board level it would be implemented by designating a point near the centre of the board as the reference point, and by routing all return conductors to that point.

The components on the PCB would be arranged in a circle round the star point, and the signal conductors would be routed circumferentially. In this configuration, every signal loop would enclose a segment of the circle. Strong magnetic coupling would exist between the loops. The configuration would suffer a high level of self-induced interference.

Ian Johnson does not dispute the reasoning given in the August article. He chooses to quote his own example - that of a power amplifier, which had been divided into two stages, designated 'low power' and 'high power'. He reasons that, 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.

I am all in favour of the concept of segregation (of system modules), but fail to see how such segregation can be achieved with a star point ground. The ground references of the two stages would be at different voltages, due to the effect of currents in the supply conductors.

The problem of transmitting an interference-free signal from the low power stage to the high power stage could be solved by using a twin conductor to carry the signal and by installing a differential input amplifier in the high power stage to reject common-mode interference.

In this new configuration, the ground reference terminal for the signal-under-review would be located in the low power section, adjacent to the signal terminal. It would not be the terminal designated as the star point ground. The configuration could no longer be described as having a 'star point ground'.

Another defender of the 'star point ground' is John Woodgate (EW June 2002). For him, the term is synonymous with "zero-volt reference". He declares that it appears as the "bottom line" in circuit diagrams drawn with British conventions. A line is not a point. How can a point be represented by a line?

It would appear that at least three different interpretations of the term 'star point ground' exist. Those of Ian Johnson, John Woodgate, and that defined in the article 'Designing for EMC". There are more.

Many words have been written on the topic of electromagnetic compatibility, and the language is replete with jargon and generalisation. 'Single-point ground' is but one example.

It seems odd that we, as engineers, prefer to use language which cloaks the subject of EMC with an aura of mystery. Badges labelled 'EMC Guru' have been observed on the lapels of delegates to EMC conferences. This treatment is not applied to other aspects of design, i.e. power consumption, frequency response, functional performance, size, mass, reliability, safety, and cost. Electromagnetism is a branch of science, not a magical phenomenon.

We have a vast array of analytical tools to hand. Of these tools, the most useful to anyone constructing an item of electronic equipment is the circuit diagram.

The circuit model was a wonderful invention. On the one hand, it enables anyone who looks at it to deduce the function of the hardware it represents. On the other hand, it provides information for a set of mathematical equations to be written out. This set of equations enables the performance of the equipment to be defined.

Frequency analysis can be used to produce frequency response graphs. Laplace transforms can be use to predict the output waveforms. If the calculations become onerous, Circuit Analysis software and Mathematical software are readily available to ease the task.

Normal use of a circuit model depicts conductors as lines, and it is assumed that the voltage at one end of the line is identical to the voltage at the other end. However, it is well known that every conductor possesses the properties of inductance, capacitance and resistance.

If these properties were to be represented by components on a circuit model, then that model could be used to analyse the coupling of signals from one part of the system to another. Further development of the model would allow the signals in the system to be related to the electromagnetic field.

As with any filter circuit, the predominance of inductance and capacitance will result in resonances. There will be peaks in the response of the cross coupling of wanted and unwanted signals, and it is at these peaks that interference problems occur. One task for the designer is to ensure that such peaks do not occur in the bandwidth occupied by the desired signal.

This task can be undertaken by creating a circuit model of the configuration-under-review, analysing it to define the interference coupling, and then repeating the exercise to define its response to the desired signal. It is possible to predict the performance in the presence of interference, and to predict the level of interference to be expected from a particular system.

Intra-system and inter-system interference problems can be solved by invoking the use of such models.

Admittedly, it does mean that old textbooks on electromagnetic theory and circuit theory need to be dusted down and reopened, to identify those gems of information which enable useful circuit models to be created.

Ian Darney
UK

More thoughts

I have been receiving Electronics World in its present and previous forms for around 30 years. My loyalty has been due to the rich selection of varied articles which, unlike some publications, do not shy away from going into a bit of mathematical detail. For a professional analogue designer like myself, it is the only UK publication, which provides anything like the input that I want.

Thus, I am disturbed by the gradual reduction in the content of the publication over the past months, and which has now become very evident with the changeover from a glued to a stapled spine.

It cost is an issue, then I would rather pay 25% more for a fuller publication than see it decline so.

Sadly, the 'Highbury' effect has not (yet?) led to any improvement. Whilst the useful and well-written articles of experienced practitioners such Ian Hickman and Cyril Batemen are always appreciated, we can well do without such poorly written articles such as 'An Electronic Universe' by Nigel Cook in the August issue. Whilst I think that the subject matter is potentially interesting (indeed, I still remember Catt et al's original articles in WW), the writing style and quality of presentation are awful - how about a few illustrations to help with the explanations, for instance.

I am a little concerned about the introduction of more computer articles, as you state in your September editorial. One of the unique attractions and great strengths of Electronics World is its bias towards the analogue side of electronics engineering. If this was not so, I would not buy it. Thus, I trust you will take care to ensure the relevance of any computer articles to the present readership. There are plenty of other publications for people whose main interest is computers. I thought the idea of a free 'readers-ads' page, mentioned in the same editorial, excellent.

Referring to the September Letters page, I agree with Mike Harrison's comment that the inclusion of long software listings in the publication is unnecessary, but am vaguely suspicious of the validity of Andy Emmerson's letter on the basis that it seems that he might also have written the editorial for the July edition. Are you sure that he is really joking when he suggests the magazine might benefit from 'larger page count, lower cover price, rename to Wireless World'?

Whilst few of us would seriously expect the cover price to fall, I think many of us would like to see a return to the higher standards of the past. Since (apparently, from your August editorial) 70% of us are electronics professionals, we are looking for content, which can meet our professional and intellectual needs. In my view, the publication has achieved this in the past by attracting the services of experienced, knowledgeable and enthusiastic electronics professionals who have the gift of conveying useful and appropriate information, in writing, in an engaging way.

I have a feeling that you might have received many more emails and letters criticising the way that Electronics World seems to be going. For the first time ever, I find myself wondering whether it is worthwhile continuing my subscription when it comes up for renewal. I would certainly appreciate hearing from you how you plan to stem the decline and bring the standard back up to its previous level.

Dr. S.T. Hughes
Southampton UK

Now I'm a few months into my editorship – I think I can explain a little about what is going on. Firstly, we have had a poor handover to our new distributors (the previous ones were owned by the old owners of EW) but we are pretty well on top of that issue now. Secondly, we've had poor continuity in our ad sales department – again partly due to a poor handover. We are now back on track with our new salesman, Reuben. As this magazine is a business like any other, it needs a combination of income from you, the readers and our loyal band of advertisers to balance the books. As we gain revenue, the magazine will grow in size and be able to offer a more diverse selection of articles. Which will in turn increase circulation, which will increase revenue etc.

The lack of illustrations for the 'Electronic Universe' article was again down to a poor handover and was basically down to an inexperienced me.

I am in no doubt about the fact that you, the readers, think that computers should only be mentioned where appropriate. We will, however, be running some articles on computing but they will take a different slant to other magazines and will be tuned to the needs of the electronic engineer.

Andy Emmerson did indeed write the July leader and I am certain he was joking when he suggested a 'larger page count, lower cover price, rename to Wireless World'? If the magazine gets more popular, then some of his suggestions could well be a possibility, however the name 'Wireless World' is still (unfortunately) owned by the former owners (Reed). As I too would like to return the magazine to its former name. - Ed

I get the message

I'm not normally prompted to put pen to paper, but correspondence in the October issue regarding the direction and content of this magazine evoked feelings that I feel bound to express. Especially John Jardine's views, almost all of which I exactly and strongly agree with. Will you please reprint JJ's letter in this issue - IMHO it merits at least one more showing to give a wider readership the opportunity to reply. I used to buy WW regularly, but now scan the front cover then perhaps the index, and buy only when the content is to my taste.

Unlike Mr. Jardine I am not a qualified electronics engineer but a, dare I say, advanced hobbyist and, I suspect, one of a significant number of such who must feel the same as I. IMHO EW must gain and retain the respect of leading professionals and enthusiasts and so motivate them to submit articles and thereby contribute to its excellence. Success breeds success; the converse is true. You choose.

Resist the temptation to include content that is other than original, leading and bleeding edge or innovative and ingenious and seriously interesting or intellectually challenging. For example, in an era when one can walk into the local hardware store and buy a programmable synthesiser tuned FM/Stereo/RDS portable with all sorts of bells and whistles for £60, or on the 'net a sophisticated FM-RDS/SW-SSB/MW/LW set for £140, we need articles on using - or designing even - the TEA1575, say, and programming micro-controllers to drive it, from the people who do it. I will buy EW regularly if it attains and maintains that high standard of content.

My desire, as an electronics enthusiast, is to build, or design and build, that which is not available commercially or which outperforms in some way that which is available commercially, or at the very least to understand what would be involved in so doing. To that end (and I know I speak for others) I need you to regard as your peers and competition not so much other mags on the news stands, but manufacturers data sheets, application notes and support forums, Usenet and other Internet resources. I suspect that the more loyal readership attracted by this approach would be willing to pay a significantly higher cover price (I for one would), and that 'big name' advertising revenue might be attracted, eventually providing you the same revenue, or more, than from a more 'popular' approach.

Finally, and this from an IS professional and computing enthusiast, I agree with Nigel Cook's view that content be broad, but absolutely not in the way that he suggests - sideways into computing or down into articles aimed at the novice. There are other mags for that! I have no problem with discussion of the design of the electronics in any part of a computer (or audio or radio or automobile or test-gear or whatever), nor with intricately associated non-electronics content, for example the loudspeaker cabinet construction details in the October issue, or software design discussion when the electronics under discussion incorporates a micro-controller. Source-code listings though, and perhaps even software design discussion, could (should?) be made available Web-only. Indeed might you not gain from making all of the content available by subscription on the Web for those for whom that is more convenient? Be courageous and different and the best.

Bill Allison
U.K.

Space this month does not permit me to reprint JJ's letter, but your comments are duly noted. And thank you for them – Ed.

Turn up the audio

Please keep the analogue audio coming thick and fast, forget all that digital rubbish; it sounds rubbish. You must know from your past experience that an old Neve mixing desk will run rings round any of these new digital pieces of crap.

Conspiracy theory eh? Not having seen the article, I presume that this refers to the fact that the mobile telephone people manage to cook people's brains with their portable microwave ovens. For a great many years, I have serviced radio microphones. The standard for these was MPT1345 for VHF systems, and this allowed an e.r.p. of 2mW for a hand held transmitter, and 10mW for a belt pack. No greater power was allowed, since it is well understood that it is dangerous to allow RF energy to radiate directly into human flesh.

The mobile telephone people suddenly managed to persuade the regulatory authorities that they should write their own standards, and set their own limits. How? Can I suggest that money had some bearing on this? We are still limited to miniscule power levels and these are heavily enforced; but the mobile people can use their subjective SAR test to push out whatever power they wish to use – then fiddle the figures afterwards so that it sounds better.

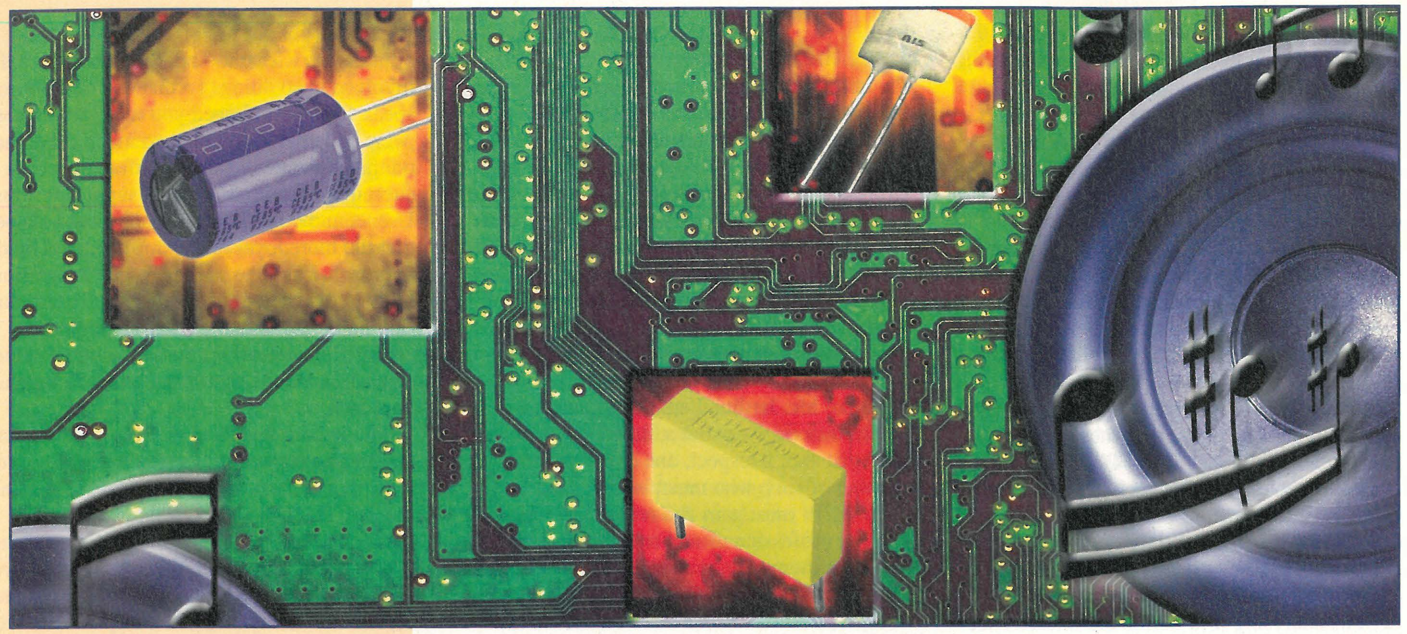
It was probably a similar thing with the recent EU directive on Vehicle End Of Life. The EU wanted the manufacturers to be responsible for the recycling of their scrap. I would imagine the meeting went something along the lines of "So, you want us to accept this directive eh. How many free, and heavily subsidised vehicles do you receive from us annually?" End of directive.

What about the WEEE directive? As it was originally written, each manufacturer was to be held responsible for recycling their own scrap. The refrigerator manufacturers have managed to get out of this very quickly. I confidently predict that when this finally comes in, goods will still be collected at the local refuse point, and each manufacturer will pay a tax to cover the recycling costs. The music industry scraps maybe 0.0001% of goods – I regularly service 30-year-old product; but we are going to have to pay the same amount as computer manufacturers – ever tried to get a thirty-week-old computer repaired?

Now I have that off of my chest, what about the proposed changes to the LVD? I attended a meeting last month at the DTI, on behalf of the Music Industries Association. Basically, the vast majority of Europe wants to remove the 50V lower limit. Only four EU members are opposing it, so it will probably go through. Can you imagine the extra work this will involve, testing absolutely every product for electrical safety? For me, no doubt it will be a re-run of the EMC directive; I will receive a note from our MD telling me to sort it out.

Kevin Aston
UK

I feel I know you! For the non-audio mixing desk experts out there – a certain Mr. Rupert Neve did indeed design some of best audio circuits ever. His compressors, EQ designs and microphone amplifiers are still used in the poshest recording studios, because they sound better than the harder 'digital' offerings - Ed ■



Capacitor sound 5

- 1μF choice - Electrolytic or Film?

Many capacitors introduce distortions onto a pure sinewave test signal. In some instances distortion results from the unfavourable loading which the capacitor imposes onto its valve or semiconductor driver, though more often, the capacitor generates the distortion within itself. Cyril Bateman continues his capacitive deliberations

For too long capacitor generated distortions have been the subject of much speculation and opinion. Capacitors are not categorised for distortion in manufacture, so a distorting capacitor would not be accepted as reject by its maker, but this can now be measured. Using my easily replicated test method, audio enthusiasts can select capacitors when upgrading their equipment and designers can select capacitors for each circuit requirement.

For 100nF capacitance we find the lowest distortions are generated by choosing either C0G multilayer ceramic, metallised film Polyphenylene Sulphide (PPS) or double metallised film electrodes with Polypropylene (PP) film.[1]

At 1μF, C0G ceramic types are not generally available, reducing our low distortion choice to the above two film types or a selected metallised Polyethylene Terephthalate (PET). To guarantee low distortion we found that metallised PET types should be distortion tested and used with no bias or with modest DC bias voltages. The PPS and PP capacitor types produce exceptionally low distortions but are larger and more expensive. **Fig. 1.**

To minimise costs at 1μF and above, many designers elect to use low cost polar aluminium electrolytic capacitors. We now explore this option.

Electrolytic capacitors

At room temperature and 1kHz, a typical 1μF 63 volt polar electrolytic capacitor can sustain some 30mA AC current. By measuring its distortion at 1kHz we obtain a direct comparison of polar electrolytic distortions with the film capacitors of my last article.

There are a lot of myths surrounding the aluminium electrolytic capacitor. As with other capacitor types, much has been written about the sound distortions they cause. However of all capacitor types, electrolytics are the most complex and the least well understood. Many myths, specific to electrolytics have emerged, based more on speculation than on fact.

a) Aluminium electrolytic capacitor dielectric has extremely high 'k'.

b) Electrolytic capacitor distortion is mostly third harmonic.

c) For minimum distortion, electrolytic capacitors should be biased to half rated voltage.

d) Back to back polarised capacitors, biased by the supply rail, minimise distortion.

e) High ESR Electrolytics degrade sound quality, low ESR is always best.

f) Electrolytics are highly inductive at audio frequencies.

g) High voltage electrolytics sound the best.

A working knowledge of electrolytic construction combined with careful distortion measurements, leads to somewhat different conclusions.

Polar Aluminium electrolytic construction

To begin to understand an electrolytic capacitor we must explore how it differs from other capacitor types including Tantalum.

Every traditional aluminium electrolytic capacitor actually comprises two polar capacitors in series, connected back to back.[2]

The dielectric for the wanted capacitance is a thin aluminium oxide coating that intimately covers the 'anode' foil. The metal core of this anode foil, acts as one capacitor electrode. The second electrode is provided by a conductive electrolyte surrounding the anode foil.

A 'cathode' foil is used to make electrical contact between this electrolyte and the lead-out wire. This cathode foil is covered by a much thinner, naturally occurring aluminium oxide, the dielectric for our second capacitor. Electrically similar to oxide produced using a 1 to 1.5 volt 'forming' voltage, capacitance of this cathode is many times that of the anode.

The effective surface area of the anode and cathode foils is much enlarged by mechanical and electro-chemical etching. Low voltage capacitor foil areas may be increased perhaps one hundred times larger than the foils superficial or visible area. In this process a myriad of minute tunnels are created in the aluminium foils, which become sponge like and porous.[2]

An extremely thin layer of dielectric, aluminium oxide with a 'k' of eight,[3] is electro-chemically 'formed' or grown on the surface of the anode foil. Depending on the desired end use, a general-purpose capacitor may be formed at 1.25 times, a long life capacitor to double its rated voltage.

The thickness of this dielectric oxide is self limiting, being controlled by the voltage used in the forming process. As thickness approaches 14 Angstrom for each forming volt applied, oxide growth slows down and almost ceases.[2]

Because aluminium oxide takes up more space than the aluminium which is converted in the 'forming' process, different etching methods are used according to the intended forming voltage. For the lowest voltage capacitors, the most minute tunnels are etched into both foils.

Formed to 50 volts, oxide growth would completely fill these minute tunnels. The etching process is adapted to produce somewhat larger tunnels, which can be formed - perhaps to 100 volts. For higher voltages, progressively larger tunnels must be etched.[2] Becromal (one supplier of capacitor foils) lists some fourteen different grades of etched anode and a bigger selection of cathode foils.

As capacitor rated voltage increases, less conductive electrolytes and thicker separator tissues must be used. To reduce element size and cost, thinner, lower gain cathode foils may be chosen.

These changes combine to produce a near optimum quality, low tanδ, low distorting capacitor when rated for 40 to 63 volt working, with notably poorer qualities above 100 volt and at the lowest voltage ratings.

Assembly

The required length of anode and a slightly longer length of cathode foil are wound together, cathode foil out onto a small rotating spindle. To minimise mechanical damage to the extremely thin dielectric oxide coating, the foils are interwound together with soft insulating separators. Thin 'Kraft' or 'Rag' tissue paper the most common.

Aluminium has an electro-chemical potential of +1.66v. To avoid corrosion, no metal other than aluminium may be used inside the capacitor case. The external lead wires, copper at -0.337V or steel at +0.44V, must be excluded from all contact with electrolyte.

Prior to winding the element, thin aluminium connecting 'tabs' are mechanically and electrically connected to both foils. The most common method is 'eyeletting', when a shaped needle pierces both the connecting tab and its foil. Small 'ears' of tab material are turned over and well flattened down, effectively riveting both parts together. **Fig. 2.**

Cold pressure welds, seen in this photo connecting the aluminium 'tabs' to the outer tag rivets, provide the most reliable, low and linear resistance, connection of aluminium to aluminium. By applying pressure over small areas, metal is forced to flow between the two items, which become permanently welded together. This method is often used to replace 'eyeletting' in the best constructed capacitors. The completed winding is vacuum impregnated with electrolyte, which becomes absorbed into both foils and separator papers. Producing a low resistance connection between the anode and cathode foil capacitances.

Bi-polar Aluminium electrolytic capacitor construction

A bi-polar electrolytic is made in exactly the same way as a polar capacitor, with one significant difference. In place of the cathode foil, we use a second anode foil. We still have two polar capacitances in series, back to back. Both now the same value and working voltage. This bi-polar capacitor will measure half the capacitance of either anode foil - to make the required value, two anode foils, each double the desired capacitance, are used.

Aluminium electrolytic capacitor designers are accustomed to mixing and matching their available materials, to suit the capacitor's end application. So it should not surprise that some designs are semi bi-polar, i.e. they are made using a lower voltage deliberately 'formed' anode foil as cathode.

Equivalent circuit

Using this constructional background, we can deduce an equivalent circuit for a polar aluminium electrolytic capacitor. **Fig. 3**

Dielectric Oxide

Aluminium oxide has a 'k' of eight,[3] similar to that of C0G ceramic or impregnated paper capacitors. It is rather higher than PET, which at 3.3, has the highest 'k' of commonly used films. A low value compared to the

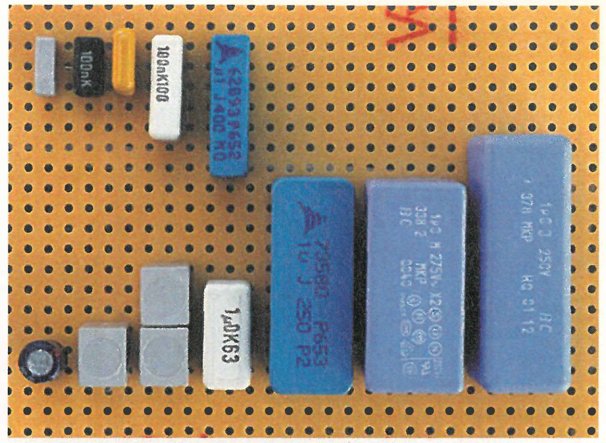


Figure 1: Bottom row left 1μF, the best electrolytic, the Bi-polar, was outperformed by the 470 type 63v metallised PET capacitor. The SMR capacitor is fourth and the B32653 fifth from left. Top row 0.1μF, the 50v and 100v SMR capacitors second and fourth, the B32652 fifth from left.

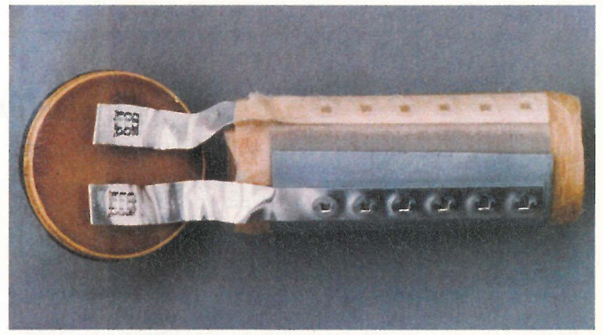


Figure 2: The 'eyeletting' type connections most often used to connect aluminium lead out tabs to the centres of both cathode and anode foils. For clarity the outermost anode and cathode foil turns have been removed. The cold pressure welds connecting these tabs to the tag rivets can be seen.

'k' of several thousand, found in X7R and Z5U ceramics.[4]

While the impregnant used in paper capacitors is an insulator and acts as the dielectric, the dielectric used in electrolytic capacitors is a conductor so cannot be a dielectric. This electrolyte is used to provide a low resistance connection between the two capacitors. More significant than 'k' value is dielectric thickness. Large capacitance values are possible because the dielectric of a 50 volt aluminium electrolytic capacitor is some 100 times thinner than that used in a metallised film capacitor. Ref.2

As a result, electrolytic capacitors are sensitive to dielectric absorption effects.

The dielectric oxide film has a measurable voltage coefficient of capacitance. When DC biased, the measured capacitance of a 1μF 63 volt capacitor increased 0.15% at -0.5 volt. Initially decreasing 0.05% at +0.5 volt, capacitance then increased to +0.16% at +10 volt.

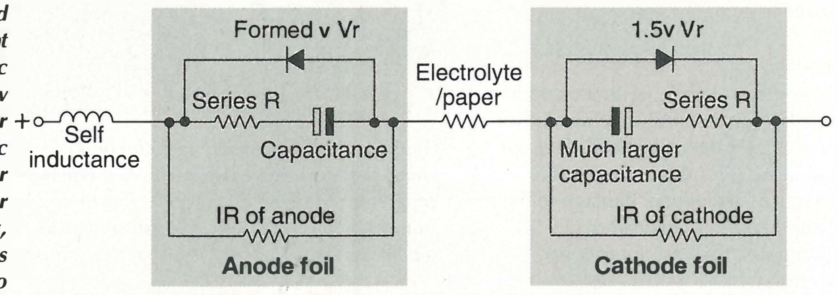


Figure 3: This simplified equivalent schematic illustrates how a polar electrolytic capacitor behaves. For clarity, components needed to account for dielectric absorption, are omitted.

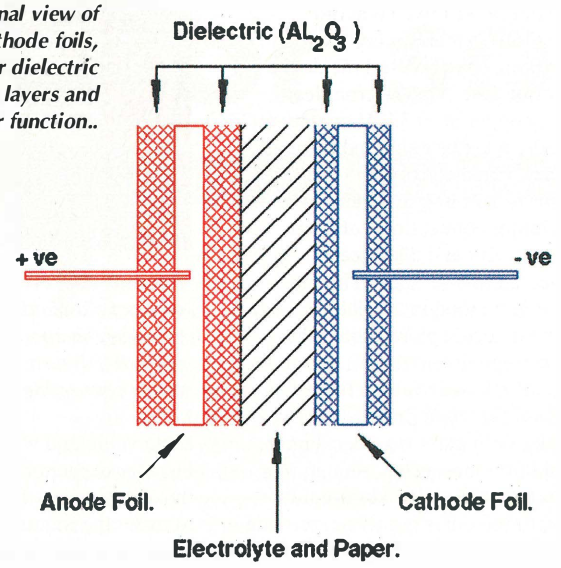


Figure 3a: Sectional view of anode and cathode foils, showing their dielectric oxide layers and electrolyte/paper function..

Voltage effects

We explore these voltage effects by measuring the distortion produced by a 1μF 63 volt polar electrolytic capacitor, subject to different AC test voltages. Commencing with 0.1 volt, capacitor distortion was measured at 0.1 volt increments to 1 volt. Initially we test with no bias, then with various DC bias voltages. Remember these voltages are those measured across the capacitor terminals and not the generator set voltage. Small test voltages reduce measurement dynamic range. Distortion of the test capacitor will be compared with those produced by a near perfect film capacitor, tested the same as reference. All tests use my DC bias buffer and two frequencies, 100Hz/1kHz to observe intermodulation.

Electrolytic capacitor behaviour varies with temperature. To minimise the affect of temperature changes, all reported tests were performed at constant room temperature. Unless otherwise stated, all voltages are RMS, measured using a DMM.

Without DC bias

Notably larger distortions were produced by this electrolytic than the film capacitor, even with a test signal as small as 0.1 volt, across the capacitor.

Capacitance of an electrolytic

The high capacitances available in an electrolytic are the result of the effective surface area of the etched and 'formed' anode foil combined with its exceptionally thin dielectric. This effective area is many times larger than the apparent or visible surface area. The extremely thin, electro-chemically 'formed' dielectric oxide film has a modest 'k' value of eight.[3, 6]

$$\text{capacitance} = \frac{\text{electrode area x 'k' x 0.0885}}{\text{dielectric thickness.}} \text{ in pF/cm.}$$

This increase in area or 'gain', is greatest for very low voltage rated capacitors, reducing with increasing voltage.

The cathode foil is covered by the oxide film which coats all aluminium surfaces once exposed to air. Some 20 Angstroms thick, it is equivalent to a 1.5 volt electro-chemically formed oxide. Much thinner than that 'formed' on the anode foil, this cathode foil oxide creates our second capacitor. It has a small usable voltage and much larger capacitance than the anode foil.[2] **Fig.3**

This naturally occurring, extremely thin, low quality cathode foil oxide, has increased voltage coefficient than the anode foil. This cathode capacitor allows an aluminium electrolyte to operate on small AC voltages, without polarisation. Correctly polarised the 'formed' aluminium oxide dielectric on the anode foil is an excellent insulator. When reverse polarised it becomes a low resistance as though a diode has been connected in parallel with a good capacitor.

In similar fashion, the naturally occurring cathode oxide film behaves like a capacitor in parallel with a diode. This diode's polarity is in opposition with that of the anode. Because the cathode oxide is thinner, it produces a more leaky diode. The capacitor should never be reverse polarised. Any DC polarisation voltage must be correctly applied with the positive voltage to the capacitor's anode terminal.

Tested with a 0.3 volt signal, distortion of this typical 1μF 63 volt polar electrolytic capacitor, dominated by second harmonic, measured 0.00115% - almost three times greater than the reference capacitor. **Fig. 4.**

When the peak of the AC voltage applied across this unbiased polar capacitor exceeds some 0.5 volt, the cathode foil's voltage dependant effects increase. Tested at 0.4 volt RMS, both harmonics increase relative to the small change in test signal. Second harmonic voltage has almost doubled compared to the 0.3 volt test. Distortion is now four times greater than our reference capacitor. **Fig. 5.**

When the peak voltage across this capacitor exceeds some 0.8 volt, intermodulation distortions appear. Tested at 0.7 volt RMS, second and third harmonic levels have increased much faster than the test voltage. Distortion, dominated by the second harmonic, is now ten times greater than our reference capacitor. **Fig. 6.**

When subject to a 1 volt sinewave, the cathode capacitance varies even more and its diode may conduct on signal peaks. Much larger increases of distortion result, now 22.4 times greater than measured on the reference capacitor. **Fig. 7**

The above voltages apply to this test capacitor. With other combinations of anode voltage and cathode foil, these voltages will vary. With larger capacitance and lower voltage capacitors the same effects are observed, but frequently at smaller voltages.

Regardless of capacitance, working voltage or manufacturer, the second harmonic was the largest distortion component for every unbiased polar electrolytic capacitor measured.

Myth

In the past various writers have stated that electrolytic distortion commences when a capacitor is subject to 1.4 volts peak, or 1 volt RMS sinewave. Doug Self once described this 1.4 volts as the voltage "which appears to be when depolarisation occurs in practise. Naturally distortion results as the capacitor dielectric film starts to come undone." [5]

On both counts this is wrong. As we have seen, significant distortions occur at much lower voltages.

While the thin aluminium oxide film

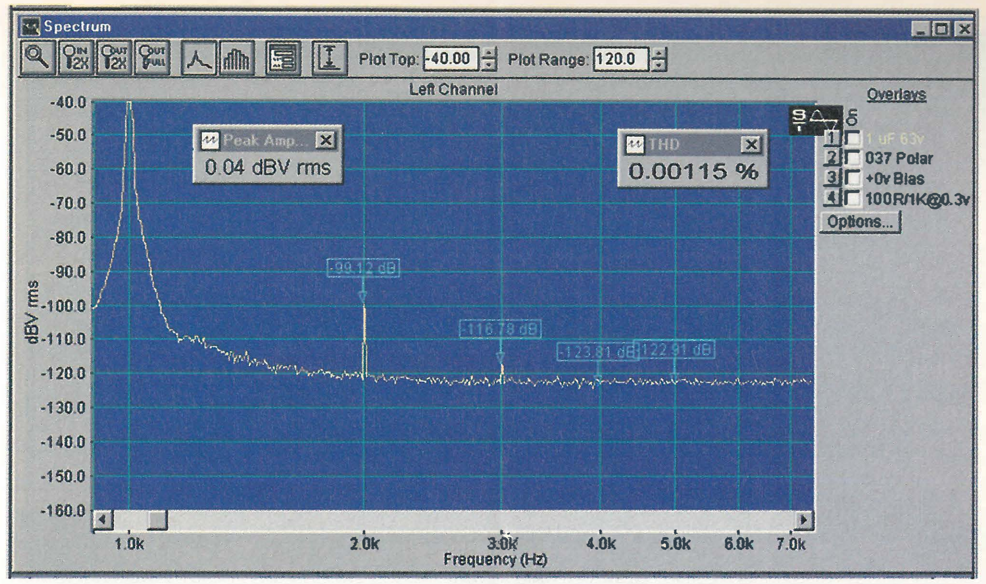


Figure 4: Distortions measured on our 1μF 63 volt polar capacitor, using a 0.3 volt test signal without DC bias. Note how the large second harmonic component dominates all others.

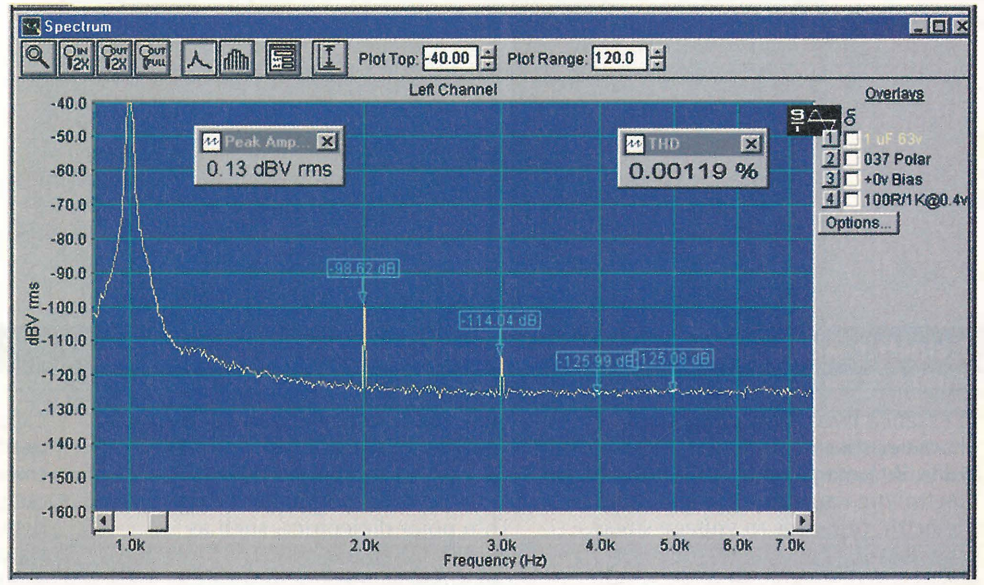


Figure 5: Both second and third harmonics have increased relative to the 0.4 volt test signal. The second much more than the third. Intermodulation components remain buried in the noise floor.

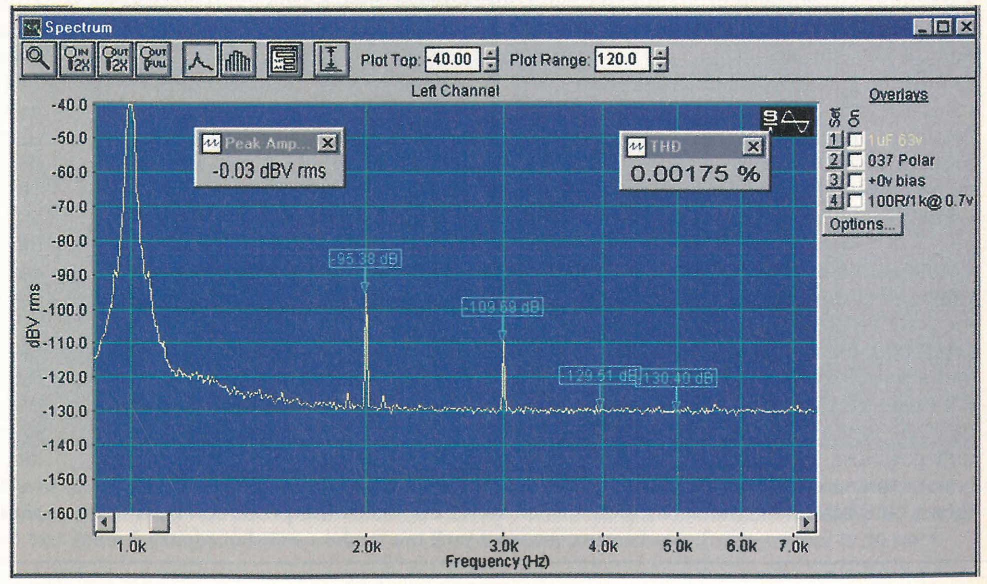


Figure 6: At 0.7 volt, with the third harmonic some -110dB below the test signal, intermodulation products can be seen either side of the second harmonic.

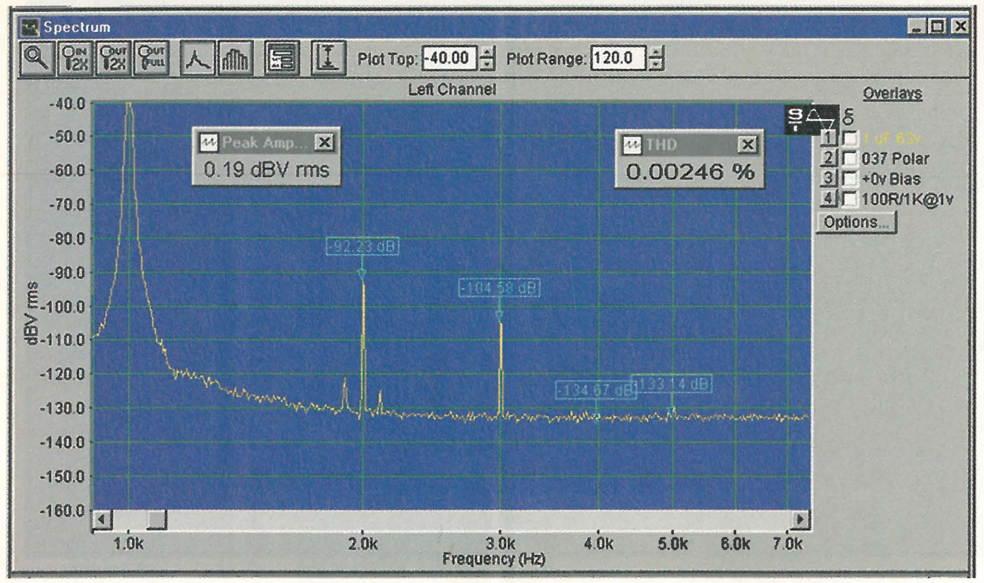


Figure 7: With a 1 volt test signal and no bias, the capacitor is producing 22.4 times more distortion than the film reference capacitor. Second and third harmonic components have increased out of all proportion to the test signal.

is easily mechanically damaged, like anodised aluminium, electro-chemically it is extremely robust. It requires substantial time and/or energy, to revert the aluminium oxide structure. Capacitor specifications permit short-term voltage reversals up to 1.5 volts, when the capacitor must remain undamaged.

If severely abused by significant reverse voltage or excessive ripple current, a conventional aluminium electrolytic may explode. Not because the aluminium oxide film has deteriorated, but simply because these conditions result in large internal currents. Hydrolysis releases gases from the electrolyte and internal pressure increases until the capacitor case breaks.

To help interpret the above results, I converted the 2nd and 3rd harmonic distortion levels into µV. Plotted against test voltage, both harmonic voltages clearly increase ever more rapidly with increase in test voltage. **Fig. 8**

With DC bias

Looking once more at our equivalent circuit we see the anode and cathode foil leakage resistances with the electrolyte, create a DC potential divider chain. Application of a small positive DC bias with no AC signal, raises the electrolyte voltage above the negative terminal, see Fig. 3.

However subject to an AC test signal and DC bias, the anode and cathode capacitance values with their respective diodes, modify the electrolyte's potential. Tested with AC only, the electrolyte potential becomes slightly negative with respect to the negative terminal, resulting in an increase of second harmonic distortion. Subject to a small DC bias and an AC signal, the electrolyte potential increases. It can become zero or even slightly positive with respect to the negative terminal, reducing second harmonic distortion.

Dielectric Absorption

In essence two major dielectric characteristics exist - polar and non-polar. By polar, I am not referring to an electrolytic capacitor, but the way a dielectric responds to voltage stress. This stress is the voltage gradient across the dielectric, and not simply the applied voltage. It is stress in volts per micron, which matters.

Vacuum and air, are little affected by voltage stress. Solid dielectrics which behave in a similar fashion are termed 'non-polar'. Most solid dielectrics and insulators are affected to some extent, increasing roughly in line with their dielectric constant or 'k' value. This 'k' value is the increase in capacitance when the dielectric is used to displace air.

When a dielectric is subject to 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 stress produces a heat rise in the dielectric, resulting in dielectric loss.

Non-polar dielectrics exhibit small losses but polar dielectrics are much more lossy. Having been charged to a voltage, it takes longer for the electron spin orbits in a polar dielectric to return to their original uncharged state. Thin polar dielectrics, such as aluminium oxide, produce large, easily measured 'dielectric absorption' effects.

Dielectric behaviour with voltage depends on the voltage gradient in volts/micron and the characteristics of the dielectric. Its effects are more readily apparent at low voltages with thin dielectric. The dielectric used in low voltage electrolytics is exceptionally thin. Consequently we find increased effects from dielectric absorption when measuring these types.

Dielectric absorption is measured by fully charging the capacitor for several minutes, followed by a rapid discharge into a low value resistor for a few seconds. The capacitor is then left to rest for some time after which any 'recovered' voltage is measured. The ratio of recovered voltage to charge voltage, is called dielectric absorption.

So how might dielectric absorption affect the distortion produced by a capacitor? Many fanciful, even lurid descriptions can found, describing smearing, time delays and signal compression. My capacitance and distortion measurements do not support these claims. The main difference I found which clearly does relate to dielectric absorption, is the magnitude of the second harmonic. This increases with applied voltage, especially so with electrolytic capacitors.

My measurements indicate it is the level of third and odd harmonics generated by the capacitor that determines intermodulation products. These harmonics are little affected by DC bias on the capacitor. No doubt intermodulation distortions would contribute to a muddled or smeared background sound.

Third harmonic distortion depends on the peak voltage across the capacitor. For a given signal level, voltage across the capacitor will be greatest at the lowest frequencies. A low frequency, large signal peak, can trigger intermodulation distortions, which then affects higher frequencies.

These changes in electrolyte potential are easily confirmed by simulation using our equivalent circuit. This positive shift has a beneficial reduction on the AC signal non-linearity produced by the capacitor, measurable as a substantial reduction in second harmonic distortion. With optimum DC bias, the second harmonic may become smaller in amplitude than the third harmonic. Tested at 1 volt with 6 volt DC bias, distortion was reduced from 22.4 to 6.5 times greater than the reference capacitor. **Fig. 9**

Myth disproved

Only when a polar electrolytic capacitor is biased near its optimum voltage does second harmonic reduce, third harmonic may then dominate. Optimum bias varies with the applied

Technical Support

Interested readers are free to build a system for personal use or educational use in schools and colleges. Commercial users and replicators should first contact the author.

A professionally produced set of three FR4 printed circuit boards, with solder resist and legends, for the 1kHz signal generator, the output buffer amplifier/notch filter/pre-amplifier and the DC bias buffer network, comprising a 'with DC bias, single frequency, distortion test system'. Complete with component parts lists and assembly notes, the set of three boards costs £32.50.

Post/packing to UK address £2.50. Post/packing to EU address £3.50, rest of world £5.50.

As a service to Non-UK readers, but only if ordered together with the above PCB's, I can now supply one four gang potentiometer with each set of boards, re-tinned and tested, for an additional £5.00 inclusive of postage.

Falcon Electronics (EW September) has these potentiometers in stock.

Postal Orders or Cheques, for pounds sterling only, to C. Bateman. 'Nimrod' New Road. ACLE. Norfolk, NR13 3BD, England.

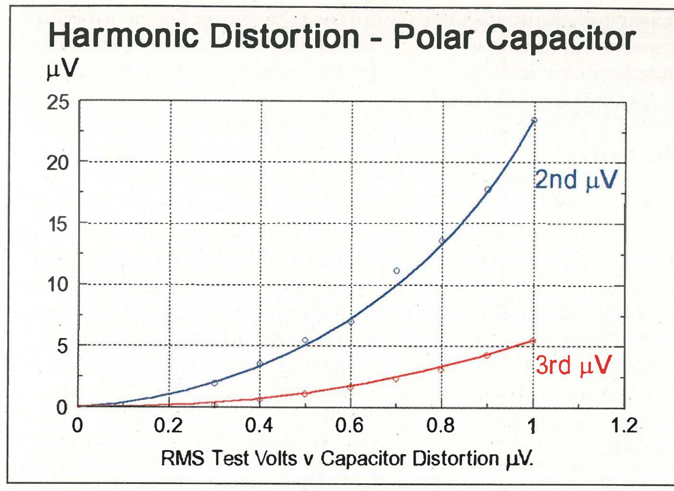


Figure 8: The dB levels in the above plots tend to disguise distortion increase with test voltage. Translating measured dB values into µV, this plot of distortion versus test signal provides a much clearer picture of our unbiased polar capacitor.

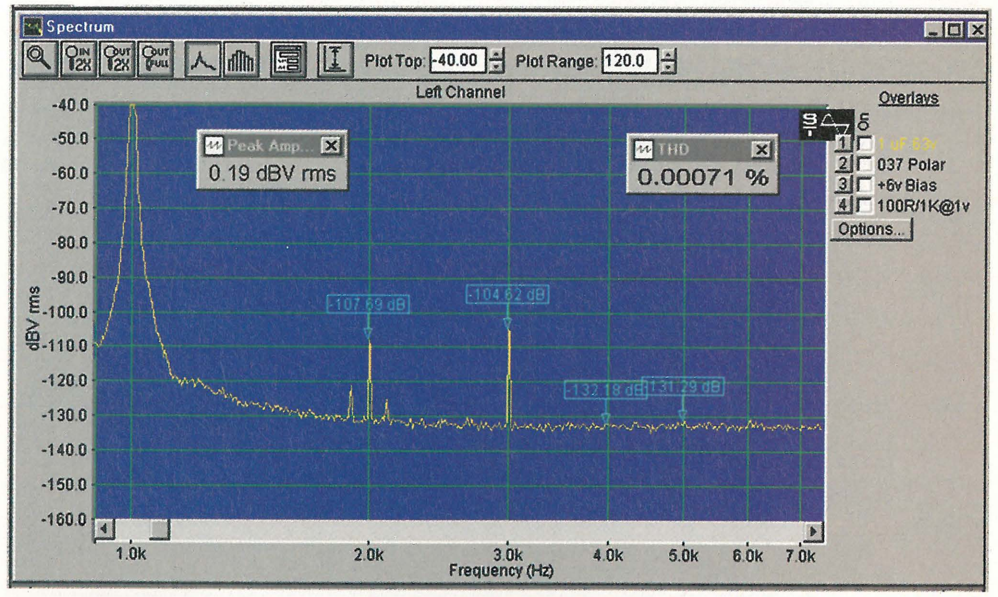


Figure 9: Measured as for figure 7 but using a 6 volt DC bias. Notice how the third harmonic and the intermodulation products remain constant despite the dramatic reduction in second harmonic level with this DC bias.

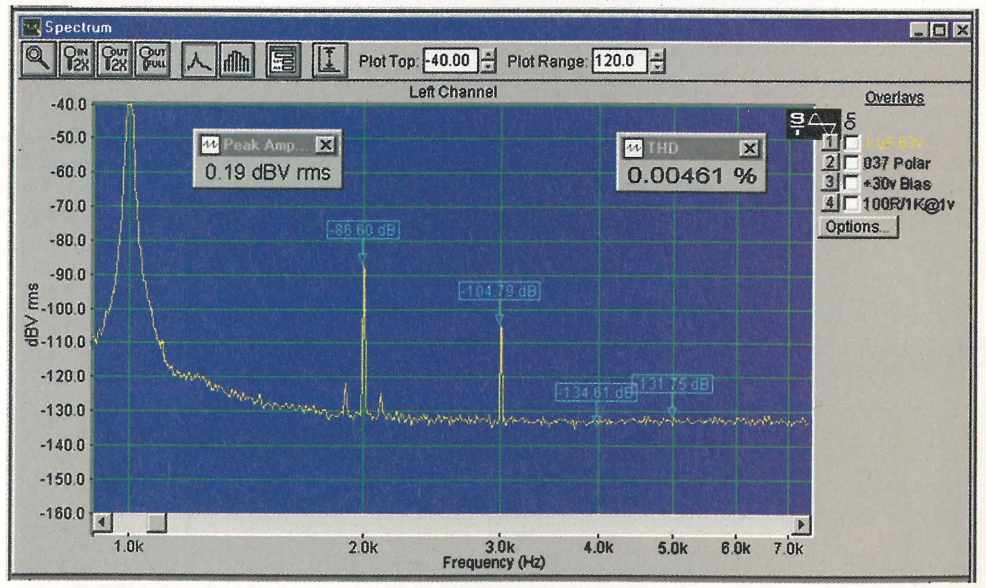


Figure 10: Measured as for figure 7 but with 30 volt DC bias. The capacitor is polarised to one half its rated voltage, the 'myth' value. Second harmonic has increased dramatically and distortion doubled compared to no bias figure 7. Intermodulation products and third harmonic are unchanged, from no bias to 30 volt.

AC signal, capacitor construction and even from capacitor to capacitor within a batch. From my tests, it ranged from less than 1 volt to some 12 volt.

With further increase of DC bias voltage, the effects of dielectric absorption outweigh this improvement. Second harmonic distortion increases rapidly with bias voltage. I re-measured this electrolytic and the reference capacitor at 1 volt AC with 30 volt DC bias, its 'mythical' optimum. Distortions dramatically increased, now almost 42 times greater than the reference capacitor. **Fig. 10.**

These changes in second harmonic amplitude, tested with and without DC bias, clearly result from the AC and DC voltages applied, dielectric absorption and dielectric thickness/formation voltage.

Non-linear effects in the interconnections, the oxide dielectric and the electrolyte/paper combination contribute third harmonic distortion. Third harmonic distortion increases with the applied AC signal. It does not change with DC bias voltage, remaining almost constant from zero to 30 volt DC bias. **Figs. 7, 9, 10.**

With increasing AC signal, when third harmonic distortion exceeds some 0.0003% of the test signal, intermodulation distortions become visible above the measurement noise floor. Any increase in AC signal results in much increased intermodulation and harmonic distortions.

Typically the maximum signal voltage to avoid intermodulation distortion with this 1μF polar capacitor is around 0.5 to 0.6 volt. However, even at these voltages it still produces substantial harmonic distortion. **Figs. 5 and 6.**

Bi-polar capacitor voltage effects

This construction provides two near identical anode foil capacitances, each subject to half the applied AC signal. Having no low quality cathode foil capacitance, it is freed from its non-linear effects so produces negligible distortion when unbiased. Distortion at 0.00017% is ten times smaller than the single polar electrolytic and just 50% greater than our reference capacitor. **Fig. 11.**

A DC bias voltage unbalances a bi-polar capacitor, resulting in increased second harmonic distortion. With 6 volt DC bias, second harmonic increased to -107.5dB and distortion measured 0.00044%. Little more than half the polar capacitor's distortion with this bias.

Subjected to 30 volt DC bias and a 1 volt test signal, second harmonic increased to -93dB. Third and higher harmonics are unchanged. Distortion at 0.00225% is less than half that of the 1μF polar capacitor and remains free from visible intermodulation.

Two Polar capacitors back to back

Using two polar capacitors each of 2.2μF, connected in series and back to back, produces a chain of four capacitors, with a nominal 1μF capacitance.

With no bias voltage, each polar capacitor sees half the AC voltage. Second harmonic is much reduced and distortion measured 0.00034%. While substantially less than for the polar electrolytic, distortion is double that measured on the Bi-polar capacitor. **Fig. 12.**

With 6 volt DC bias, distortion of our 1μF polar capacitor reduced to 0.00071%, but more than 60% greater distortion than measured on the Bi-polar.

With 6 volt DC bias, second harmonic distortion of the back to back pair increased 20dB becoming dominant and distortion increased fivefold to 0.00169%. **Fig. 13**

At 1 volt AC, regardless of bias voltage, the single polar capacitor and the back to back pair both produced visible intermodulation.

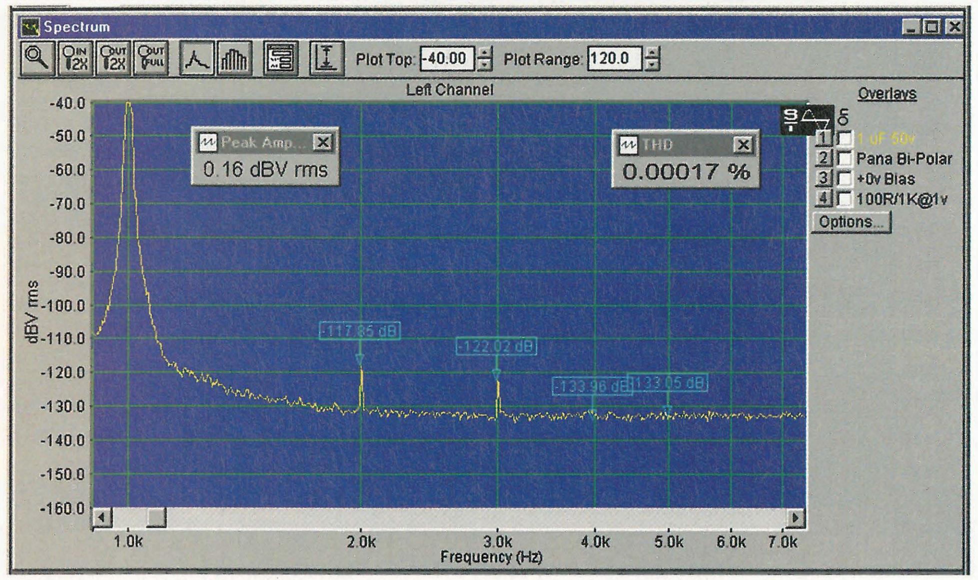


Figure 11: The bi-polar electrolytic of figure 1, measured unbiased as for figure 7. The bi-polar shows minuscule harmonic distortions and freedom from intermodulation products, compared to the polar electrolytic. Why do designers use polar electrolytic capacitors in the signal path of an amplifier?

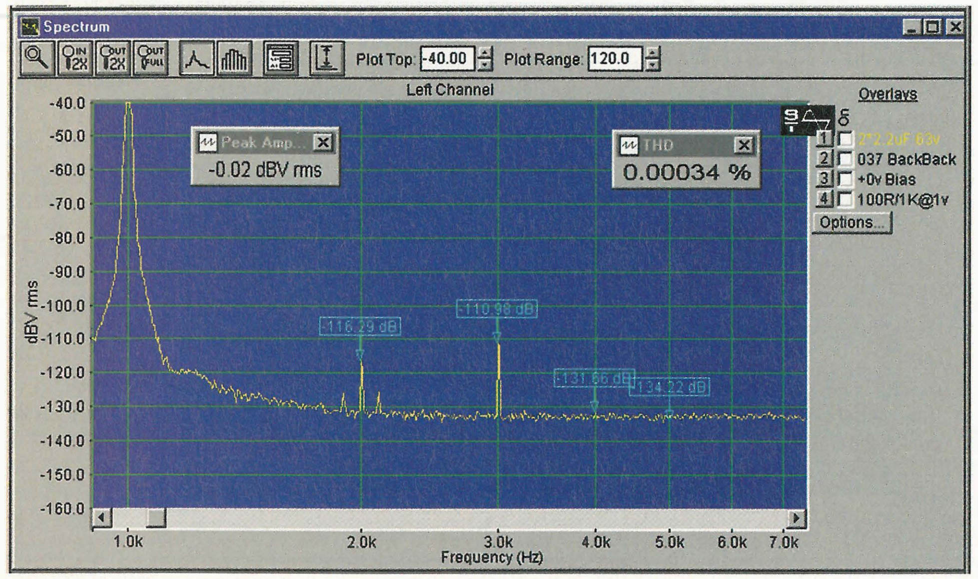


Figure 12: Two 2.2μF 63 volt polar capacitors connected back to back and measured unbiased as figure 11, produce less distortion than the polar capacitor. However with intermodulation products and double the distortion of the bi-polar capacitor, why use two polar capacitors, when one bi-polar is clearly better?

With 30 volt DC bias, second harmonic distortion for both the single polar capacitor and the back to back pair measured -86dB. Both styles produced intermodulation and similar harmonic distortions, measuring 0.00461% and 0.00472% respectively. More than double that of the bi-polar. **Fig. 14.**

In every distortion test, the bi-polar capacitor produced much lower distortions than measured on similar value and voltage polar capacitors.

Metallised film/electrolytic comparisons

To measure distortions produced by the best film capacitors in my earlier articles, I needed to use a 4 volt AC test signal. I then found several 'bad' capacitors measuring higher than normal distortion.

This 4 volt test signal is much too large when testing electrolytic capacitors. Measured using 12 volt DC bias and a 2 volt test signal, all polar electrolytics produced very high levels of distortion.

Reducing our test signal to 1 volt RMS to permit tests with and without DC bias voltage, which capacitor produces less distortion. A good electrolytic or a poor metallised PET capacitor? Regardless of bias, all polar electrolytic capacitors I measured at 1 volt generated significant levels of intermodulation distortion. The 1μF Bi-polar types were intermodulation free at 1 volt with no bias and to 30 volt DC bias. Measuring a 'known' 1μF metallised PET at 1 volt with no bias and to 30 volt DC bias, I found no visible intermodulation distortions. With 30 volt DC bias, second harmonic distortion was -100dB, distortion was 0.00089%.

The 1μF bi-polar electrolytic, tested at 1 volt and with 12 volt DC bias, measured almost identical distortions, which increased as bias increased. With 30 volt DC bias, second harmonic was -93dB and distortion measured 0.00225%, some 2.5 times worse than the PET. From these 1 volt tests the best 1μF electrolytic, the bi-polar type, was clearly beaten by the metallised PET.

Much better film capacitors were listed in my last article but at 1μF, a metallised PET capacitor provides the economic choice. For the lowest possible distortion, especially with increased signal drive or DC bias, the better quality film capacitor styles as shown in figure 1 and recommended in my last article, should be used. ■

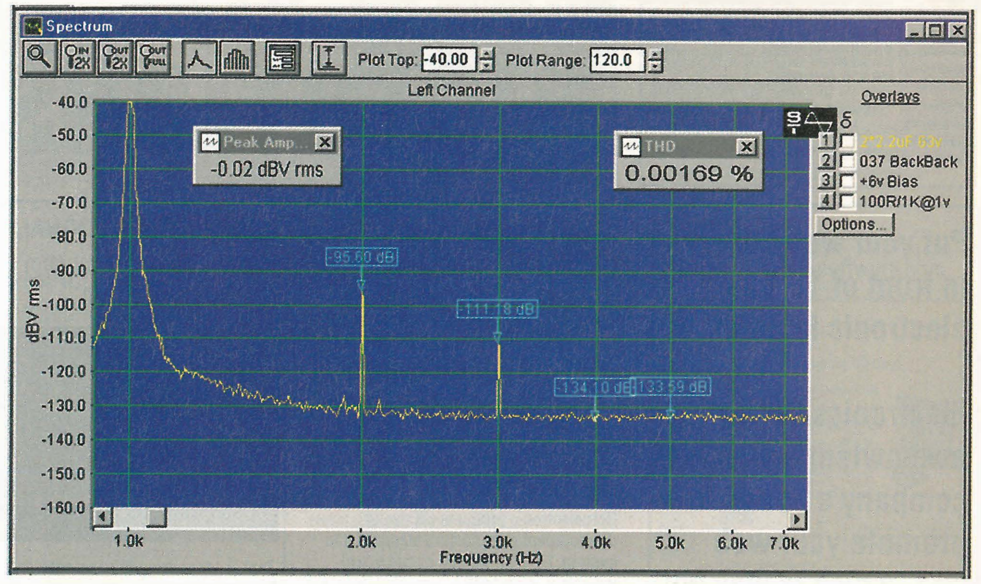


Figure 13: Measured exactly as figure 9 with 6 volt DC bias, the back to back connection produces more distortion than our single polar capacitor. The bi-polar type is much better than both. With 6 volt DC bias it measured just 0.00044% distortion and no visible intermodulation products.

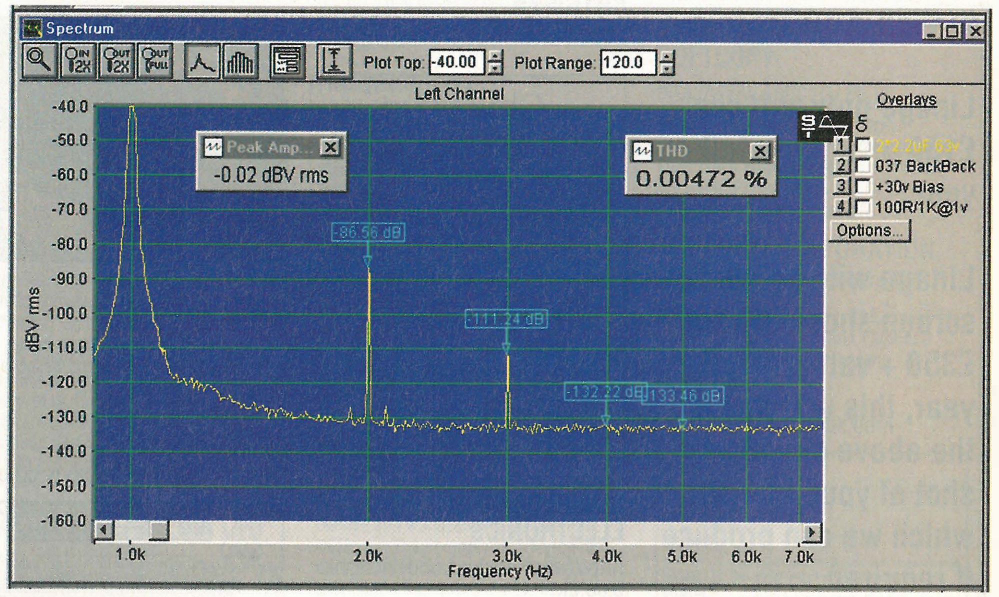


Figure 14: With DC bias increased to 30 volts, the back to back connected pair produces almost the same distortion and intermodulation products, as the single polar capacitor of Figure 10. The Bi-polar capacitor produced 0.00225%, half that of the polar or back to back capacitors and no visible intermodulation products. I repeat my questions.

References.

1. Capacitor Sounds part 4 C. Bateman EW November 2002
2. Understanding capacitors - Aluminium and tantalum Electronics World June 1998 p.495. C. Bateman
3. Reference Data for Radio Engineers.Howard Sams & Co. Inc.
4. Understanding capacitors - Ceramic.Electronics World April 1998 p.324 C. Bateman
5. Letters page. D. Self. Electronics World April 1985 p.75
6. Understanding capacitors. C. Bateman Electronics World Dec 1997 p.998

Additional Information

I am currently working to produce a CD ROM which will contain more capacitor details and figures showing many more distortion measurements than could be fitted into this series of articles, together with PDF files able to print the PCB artwork, assembly notes and parts lists.

I hope to have this CD ROM ready soon after my sixth and last article in this series is published, say mid December. Updated details in my next, the last article of this series. Expected cost £15 plus p/p.

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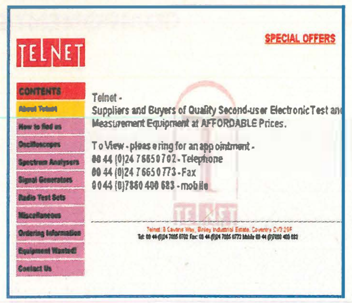

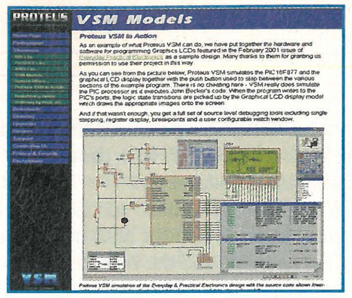

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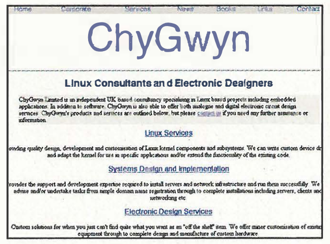

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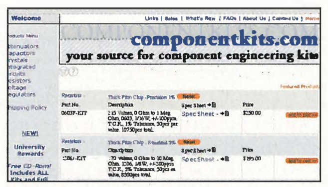

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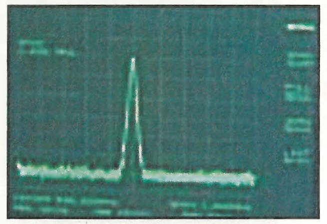

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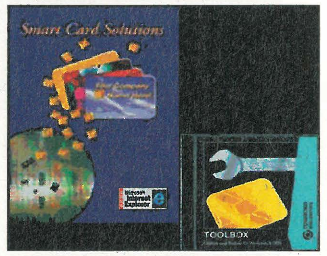

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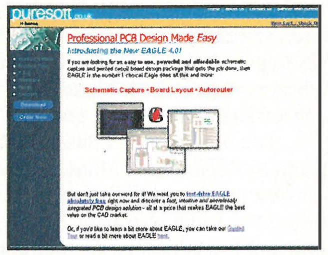

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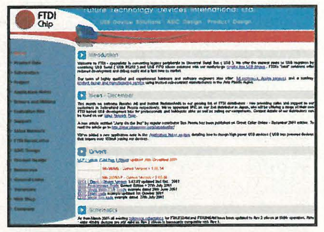

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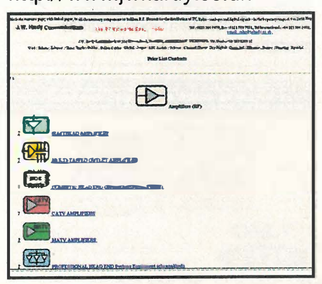

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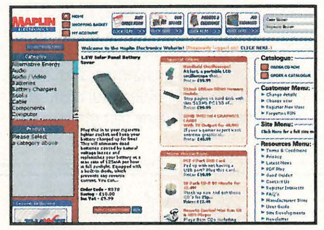

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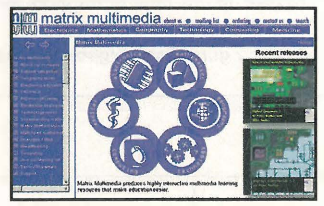

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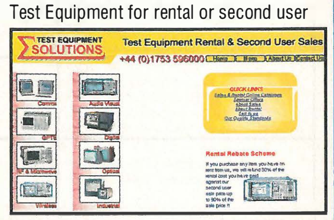

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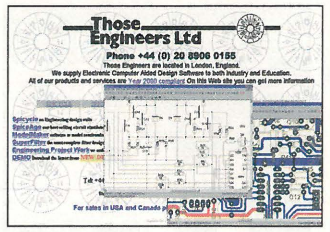

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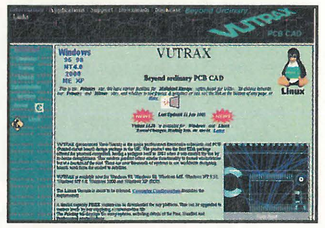

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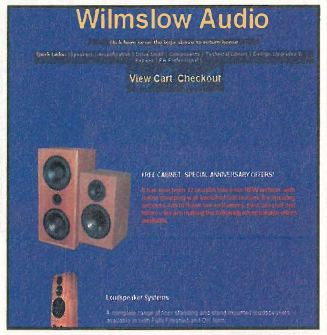

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