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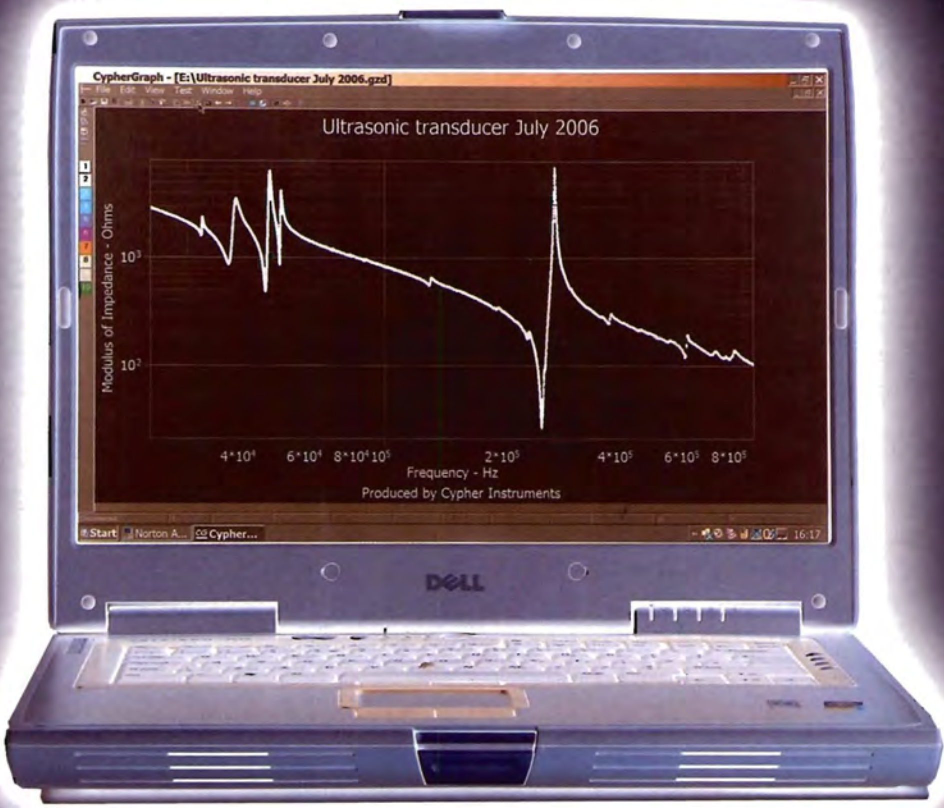

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EDITOR: Svetlana Josifovska
EMAIL: svetlana.josifovska@nexusmedia.com
EDITORIAL EMAIL: EWeditor@nexusmedia.com

EDITORIAL ADMINISTRATION: +44 (0) 1322 611274
EMAIL: EWadmin@nexusmedia.com

PRODUCTION EDITOR/DESIGNER: Tania King
EMAIL: tania.king@nexusmedia.com

DISPLAY SALES EXECUTIVE: Matthew Dawe
TEL: +44 (0) 1322 611261
EMAIL: matthew.dawe@nexusmedia.com

PRODUCTION EXECUTIVE: Dean Turner
TEL: +44 (0) 1322 611206

SUBSCRIPTIONS:
Dovetail Services
800 Guillat Avenue, Sittingbourne,
Kent, ME9 8GU
TEL: 0845 4567143
FAX: 01458 271146

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Networking gone crazy

Most of us are likely to have all the gadgets one can imagine in our homes – some of which we use, many of which we don't (but that's a separate issue). And most of us dream of that moment when these systems can work out-of-the-box seamlessly – without the need for cables, chunky user manuals, configuration software or, indeed, a service technician.

The time has come when this is possible, but is it going to be easy? At the present state of affairs, I should think not. Why?

Let's start with just some of the networking technologies available to us for the home now and in the near future.

Distributed IP networks of audio/visual systems with optional connectivity of lighting, heat/ventilation and security are already being promoted by companies such as NetStreams. In this concept, all systems get their own IP address and can be communicated with via the TCP/IP system.

Another networking technology aiming to offer triple play is Powerline Communication. You just plug your appliance (TV, DVD, speaker, projector etc) into the mains plug and away you go – everything will be communicated with via the old electricity cables.

But then, you would want whatever video you're watching to be of high quality and in real time – none of that compressed rubbish. So, HDMI (High Definition Multimedia Interface) has been devised to allow for all of your video-enabled systems, including the digital still camera and camcorder, to 'communicate' with each other to deliver a high definition video on your high-definition screen or any other high definition display of your choice.

And let's not forget wireless networking: Major moves are being made to allow in-house multimedia devices to communicate wirelessly – WLAN, ZigBee, Z-Waves, UWB, wireless USB etc.

The list of networking and communication technologies – for the house at least – is long and getting longer by the day. One has to ask: Are any of these standards likely to work with each other and deliver the promise of a seamless, reliable and secure communication and content delivery of high quality, whenever one needs it in the format of choice? Are there any alliances being formed between any of the companies championing various standards? (Even open standard devices from different manufactures are not there yet!) Are any of the designers working behind any of these standards accounting for the possibility that all of them will, at some point, need to inter-operate or at least recognise each other to accommodate the needs of the end user?

I have asked many company executives and designers these very questions but the answer is more or less always a shrug of the shoulders with a bemused look on the face.

At present, to me it seems we are heading toward a much greater problem than a solution with in-home networks – unless something is done about it pretty soon.

Svetlana Josifovska
Editor

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Avago sends a clear lighting signal to the market place

Avago Technologies, formerly the semiconductor group of Agilent Technologies, has launched three new devices for solid state lighting (SSL) applications, signalling its commitment to this market. The three devices consist of a 1W power LED (the ASMT-MxOO), an illumination and control management (ICM) device for LCD backlighting (HDJD-J833-SCROO) and an automotive-grade RGB colour sensor (ADJD-E622-QR999).

In each device, Avago has improved the packaging, the thermal efficiency, ESD protection and moisture sensitivity levels. In the ICM device, it has used a closed loop optical feedback with PWM control to get the most out of a mixed LED light. In its colour controller roadmap, Avago plans an integrated sensor and controller into a package only 3 x 3mm in size.

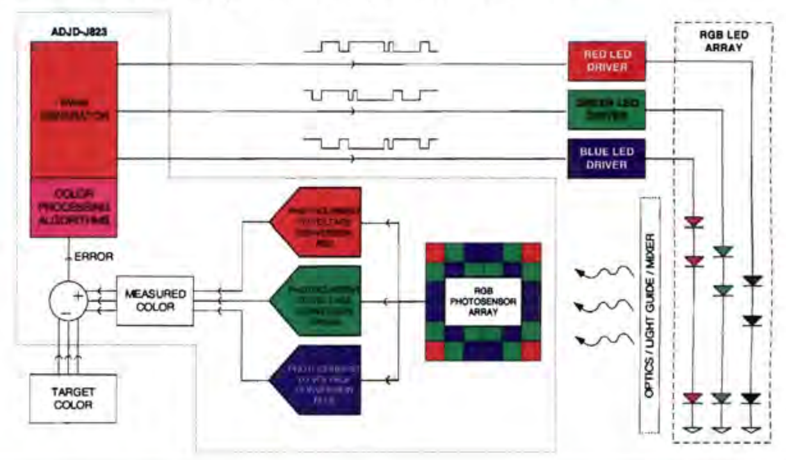
"We are late [on the market] with the 1W power LED, but that's not always a disadvantage as you can see what the others have brought out and improve on that," said Patrick Trueson, European product manager at Avago. "For example, nobody had the ideal package for the 1W power LED; some didn't offer ESD protection and others had a problem with moisture and the 'popcorn' effect. This [our LED] is a lot more comfortable to use for the customers."

The company is also developing a 25W power LED, a single-package illumination management device and smaller-package devices for back-lighting portable displays of between 3" and 7".

At present the company is not fabricating any of its dies, but is currently looking into the possibility of having a fab in-house. Its SSL portfolio falls under the optoelectronic division, but plans are to split this group into two, one of which will focus solely on the SSL market. "This will send a clear message to our customers that we are committed to this market place," added Trueson.

SSL is currently used for mood lighting in cars, trains and planes. The white LEDs are not as yet suitable for general lighting, but according to Trueson this will happen some time after 2010.

Closed-loop Optical Feedback & RGB Color Management System Overview



Growth and acquisitions on the roadmap for C-MAC

C-MAC's high-speed microelectronic and electro-optical modules are in the Eurofighter Typhoon military aircraft

C-MAC Micro-Technology, the UK based designer and manufacturer of high-precision hybrid electronics for the automotive, aerospace, communications and medical sectors, is on the acquisition path. The company is already a medium-sized, $150m business with 1000 employees, but its latest ambitions are closely linked to the appointment of Indro Mukarjee as the new CEO, who previously was a senior executive at Philips Semiconductors and Hitachi.

"We have eyes on several opportunities," Mukarjee told *Electronics World*. "Our competition is quite fragmented and it's ripe for consolidation. This industry offers consolidation opportunities horizontally – expertise that we can bring together to offer better solutions to customers; and vertically – for niche applications."

"We are not trying to compete with the main market electronics area," he added, "we want to take the Number One slot in hybrid microelectronics; we are focusing on high reliability needs."

C-MAC currently has three microelectronics plants – in Greath Yarmouth, UK, Ronse, Belgium, and Sherbrooke, Canada. There it has introduced cutting edge manufacturing such as embedded passives, embedded MEMS and thick-film printing on ceramics. Simultaneously, C-MAC continues to investigate new areas of development, such as optical electronics. "We are making investements in this area," said Mukarjee.

As part of its future growth plan, C-MAC is likely to open another manufacturing facility in Eastern Europe.

RF signals have nowhere to hide with new Tektronix spectrum analyser

Have you ever had a problem with elusive RF signals? You just know they are there, but can't quite pin them down. Tektronix claims no signal goes undetected with its new signal analyser series, the RSA6100A.

The company has created a DPX waveform image processor for these instruments, which it claims "provides first live RF presentation, revealing never before seen phenomena". They manage to capture signals as brief as 24μs.

Instrument picks up never before seen RF signals

The processor relies on many parallel stream DSPs, to process over 48,000 spectrum measurements per second. By continuously converting time domain signals into the frequency domain, the technology can display frequent and infrequent events, effectively distilling real-time computing Discrete Fourier Transforms (DFT) at frame rates far above what is perceivable by the human eye.

In addition to live RF, the waveform image processor also provides an intensity graded display to show the history of occurrence for dynamic signals and signal variations. As such, transients and signals that ordinarily could not be seen, either because they are masked by other signals or could only be deduced after time-consuming offline analysis, are easily identified and stored.

The first offerings in the new RSA6100A series are the 6.2GHz RSA6106A and 14GHz RSA6114A, with real-time bandwidth of 110MHz, and 73dB spurious-free dynamic range.

These instruments are seen as the perfect answer to the rapid expansion of digital RF applications that include radar, mobile communications, software defined radio (SDR) and cognitive radio, which become more difficult to deal with through swept spectrum and vector signal analysis. Digital RF signals carry complex modulation and change from one instant to the next, hopping frequencies, spiking briefly and then disappearing. "Most of these technologies are trying to use the same spectrum. Most of them operate by hopping or bursts and they are too fast for ordinary oscilloscopes to catch. With this [the RSA611] you can see signals which you normally don't; you can see what's happening in a [certain part of the] spectrum – what's on or off, or coming in," said Rick King, VP for real-time analysers at Tektronix.

Flash drives will threaten HDDs in computers

Malcolm Penn, the principal analyst at market research house Future Horizons, expects that flash memories will experience a significant growth over the next few years thanks to their versatility and lowering prices.

"Flash will be an amazing product line to use – it has just reached the [right] price elasticity," he said.

High capacity flash drives will be pitted against hard disc drives (HDDs) in the computer industry, for laptops and even PCs, but also in a new generation of consumer devices such as PVRs and TiVo-style machines. "The computer industry will start re-thinking the laptop and the computer. You can start to sense the beginning of a tremendous growth [for the flash drives]," said Penn.

To date, HDDs have delivered the lower price/capacity ratio needed for storage applications. However, that is changing. According to Semico Research, prices of NAND flash per gigabyte (GB) will drop to $9 by 2009 (they are currently somewhere at the $40 mark), at a price erosion rate of up to 45% per year.

Flash drives, also known as Solid State Drives (SSD), need less space and consume less power than HDDs, which is particularly good for laptops. According to analyst house In-Stat, by 2013 the SSD share of the mobile computer market could reach 50%. The total SSD market is expected to reach $4.5bn by 2010, up from $540m this year.

This is hardly surprising when flash producers are getting aggressive with their technology. Earlier this year, Samsung launched the first 32GB flash-based HDD replacement system (the average notebook has 30GB of HDD storage) based on its highest density NAND flash. In the summer it also launched a standalone 4GB SSD.

Samsung's latest 4GByte SSD

A group of 15 European semiconductor companies, intellectual property (IP) providers, electronic design automation (EDA) companies and academic institutions have joined forces to develop new methodologies and standards for efficient re-use and exchange of IP for system-on-chip (SoC) designs.
Their collaboration is the SPRINT Project, or Open SoC Design Platform for Reuse and Integration of IPs, which is partly funded by the EU and partly by the project members. The alliance will operate until the middle of 2008 to research and promote open interface and modelling standards for IP integration.
Among the SPRINT members are Philips, STMicroelectronics, Infineon, ARM, Lauterbach, TIMA and Paderborn University.

* * *

Volkswagen, Hella KGaA Hueck, NEC Electronics and 3SOFT are co-operating on the development of Automotive Open System Architecture (AUTOSAR) compatible software. They are developing a fully functional body/comfort electronic control unit (ECU) for a Volkswagen series-production vehicle. The aim of the project is to keep a daily track on the demands of the automotive industry so that real-time functionality can be met. The partners will also evaluate software integration, migration opportunities, use of resources, software runtimes, quality of specifications and cost. Initially, the AUTOSAR control unit will be used in the VW Passat model, in the effort to create an authentic test environment. Any experience gained from the project will flow back into the AUTOSAR consortium.

* * *

EU funding of €2m has been announced for a major new three-year project to develop a re-configurable photonic 'firewall on a chip'. Called WISDOM, (Wirespeed Security Domains Using Optical Monitoring), the new system will plug a major gap in the global data network security armoury – the lack of tools to implement security checks and algorithms directly at high optical data communications rates.
WISDOM will complement current electronic security techniques with optical information filtering and is being developed by a consortium led by the UK's CIP.
The sub-systems will be based on the world-leading research on high-speed (greater than 40 Gigabits/second) optical logic gates and optical processing circuits provided by project partners Avanex, CIP and Tyndall.

NDR employed in molecules to create new-generation, stable switches

A new kind of electrical switch formed of organic molecules rather than pieces of metal has been demonstrated by researchers at the Weizmann Institute of Science in Israel. Possible applications include nanoscale electronic memory and heat-sensing switches.

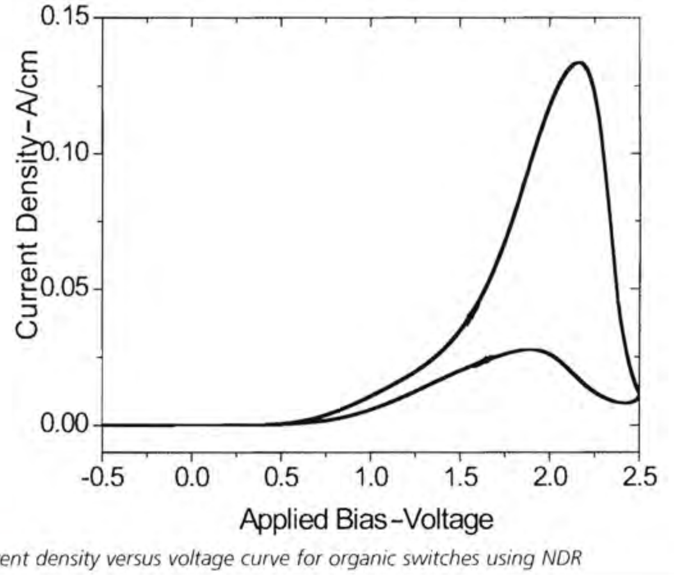
The researchers believe that the future of miniaturised electronics will be in methods that combine chemistry with nanoscience.

Their approach involved rethinking a phenomenon that drives many high-speed semiconductors: negative differential resistance (NDR) which works contrary to the normal laws of electricity, where an increase in voltage translates into a direct increase in current. In NDR, as the voltage increases, current peaks and then drops off, essentially allowing one to create a switch with no moving parts. Until now, those attempting to recreate NDR at the molecular scale had only managed it at extremely low temperatures.

Adi Solomon and Professor David Cahen of the Institute's Department of Materials and Interfaces studied the connection between metal wires and carbon-based molecules, believing it might hold part of the key to usable nanoscale NDR. They found that molecules and metal wires need chemistry between them for barriers to be lowered and the "juice" to really flow. For a given voltage, if the molecules are held to the wire by chemical bonds (in which the two are linked by shared electrons), the current flowing through them will be many times higher than if they are only touching – a mere physical bond.

Based on this hypothesis, they designed organic molecules that pass electricity through chemical bonds at a lower voltage, but through physical bonds at a higher voltage. As the voltage approaches the higher level, sulfur atoms at one end of the molecule loosen their chemical bonds with the wire, and the current drops off as the switchover occurs. But the molecules separated once the chemical bond with the wire was broken, thus preventing them from switching back to the chemically-bonded state.

In collaboration with Professor Abraham Shanzer of the Institute's Organic Chemistry Department, Cahen created long add-on tails to hold the molecules in place with a weak attraction enabling the NDR in their molecules to be stable, reversible and reproducible at room temperature.

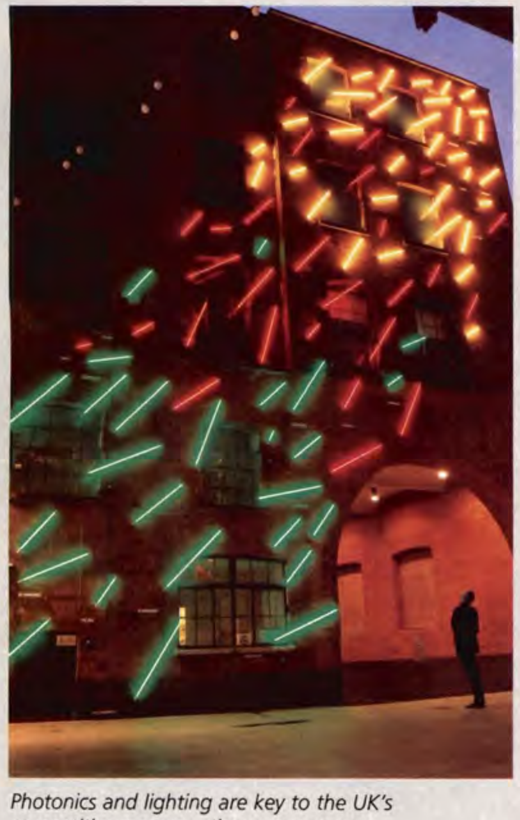


The current density versus voltage curve for organic switches using NDR

In photonics the UK government believes

In the quest to make the UK competitive in new technologies, the government launched a £3.3m photonics Knowledge Transfer Network (KTN) last month.

Lord Sainsbury, minister of science and technology, said: "Photonics has been identified as the strength in the UK to pursue. There's a good reason to believe that photonics will be as important as microelectronics is now and steam was in the 19th century."



Photonics and lighting are key to the UK's competitiveness, says the government [Image: Philips Lumileds]

According to market research organisations, the market for photonics is likely to reach $300bn by 2015, growing at an average 10% per year. New applications for photonics solutions include lab-on-a-chip, fibre to premises, security, displays, high-brightness LEDs, and storage and communications in consumer applications. There are already some opportunities where the UK photonics sector is missing out on, such as a £19m health sector programme looking at assistive technologies, and some MoD projects.

"The government has a part to play and our mission at the DTI is to encourage this [photonics development in the UK] and achieve success," said Lord Sainsbury.

Photonics was recognised as an important field back in 2000, but most of the applications developed then were telecom related. In 2005, the DTI set up the Photonics Strategy Group (PSG) to focus on the UK's photonics strategy. Last month, it produced a report, where it identified the opportunities for the UK photonics businesses within the next 5-10 years, but also what the challenges will be ahead.

"Among the key observations we made is that this is a high-growth, high-profit sector and that in the UK there are lot of [photonics] SMEs of below 30 people," said Ian Vance, chairman of the Photonics Strategy Group.

It is PSG's recommendation to create a strategic body to represent and promote the UK photonics businesses here and abroad, and give advice.

"One thing the government can do is put some money [into it] to oil the works," added Vance.

NEC Electronics unveiled a new system-in-package (SiP) technology that will allow the stacking of logic and gigabit-class memory in a single package. This will enable high-speed, high-definition image processing in portable devices.

The new SiP technology, dubbed SMAFTI (SMArt connection with Feed-Through Interposer), features a three-dimensional (3D) chip connection where the 60-micron gap and 50-micron microbump pitch between the logic and memory devices can support transmissions of up to 100Gbps. This will enable resolutions comparable to those achieved in HDTV but in mobile phones, where stringent size and power constraints are key.

SMAFTI leverages three key enabling technologies: a 50µm-pitch microbump interconnection technology, a 15µm thick feed-through interposer (FTI), based on superconnect technology, and a multichip assembly process.

* * *

New pan-European research commissioned by batteries maker Duracell has revealed that 84% of hospital medical staff rely on portable electronics equipment and 76% have run out of batteries whilst on the job. The research questioned healthcare professionals from France, Germany and the UK.

The use of medical equipment, particularly portable electronics equipment, is of increasing importance in hospitals and the research revealed that many battery-operated equipment regularly used on the job are considered mission critical by the respondents. The most frequently used battery-operated devices are beepers/pagers (90%), blood sugar measurement (68%), blood pressure measurement (61%), clinical thermometers (55%) and infusion/injection devices (48%).

* * *

For all those iPod fanatics, SDI Technologies has brought out the iHome iH5 Stereo Clock Radio (see below). Ezra Ashkenazi, president of SDI Technologies, said: "Following the reception the iH5 has received in the US, it has quickly established itself as a "must-have" accessory. We have taken the decision to extend its release to a further 23 countries, with more being added every month."

Intel gets the thumbs down

The semiconductor industry is doing well this year, says CEO and chairman of market research house Future Horizons, Malcolm Penn, but one company that bucks the trend is the old chip Goliath – Intel.

"Overall, people are having quite a good year; Intel is having a tough year – but Intel is not the semiconductor industry any more," he said.

Intel profits dropped 57% in the second quarter of this year, from the $2bn reported in second quarter of last year. Sales fell 13% to $8bn, from $9.23bn in the same period a year earlier.

Intel may have led the pack with its processors in the PC industry for many years, but some feel it has recently lost its direction. Its latest price war with AMD has lowered the average selling prices (ASPs), which is having a dragging effect on the quarter for the rest of the industry. "[Intel is] complaining that the revenues are not as good [as last year]. What do you expect when you bomb the price [of the processors]? Even my 5-year old son knows that 'units' times 'price' equals 'revenues'," said Penn.

Other industry observers think Intel is trying to re-group. "I think they will come back a lot stronger in the near future," said Scott Macrae, sales director at Atmel.

In the meantime, Texas Instruments's revenues jumped 25% to $3.7bn in the second quarter of 2006, from nearly $2.97bn reported a year earlier. Similarly, Freescale saw its profits climb to $260m in same period, with revenues reaching $1.6bn, compared to the $1.47bn reported in the second quarter last year.

TOP 10 TIPS MEASUREMENT

1. **Virtual instrumentation** – Engineers and scientists can use high-level programming software and modular measurement hardware to create user-defined solutions that meet their specific needs – very different from the proprietary, fixed functionality of traditional instruments.

2. **Don't re-invent the wheel** – By leveraging the power of the PC and commercially available technologies as part of a solution, developers can begin work on the problem immediately, shortening the project time-scale and reducing costs.

3. **Adopt a powerful and flexible architecture when connecting measurements to PCs** – No bus architecture is the silver bullet, each is ideal for different applications, whether USB, PCI, PCI Express, PXI or Ethernet.

4. **If you want accurate time-domain shape reconstruction for your periodic signal** – Don't just obey Nyquist, but sample at 5-10 times the highest frequency you are interested in!

5. **Keep the noise down** – Ensure that you have the correct field wiring for the measurement type and keep noise interference to a minimum. Find out more from **ni.com/measurementfundamentals**.

6. **The importance of accuracy** – Absolute accuracy is the specification you must use to determine the overall maximum possible error of your measurement. Remember, resolution is not the same as accuracy – calculate the accuracy of your system and find out more at **ni.com/accuracy**.

7. **System calibration** – You must ensure that your whole system has been calibrated, from transducer data sheet to measurement device. Don't forget to re-calibrate at the end of 12 or 24 month calibration cycle!

8. **Need some help?** – The cost of development and maintenance of a system can be increased significantly by a low level of support offered by software and hardware companies. Make sure that you have access to the latest software and qualified engineers to assist with technical problems.

9. **Share your ideas** – Talk with others outside of your work environment, read blogs and post to forums – ask questions, get answers and learn about new, hot topics.

10. **Finally, use National Instruments's LabVIEW** – For 20 years, NI LabVIEW graphical development has revolutionised the way engineers and scientists create flexible and scaleable test, measurement and control applications rapidly and at minimal cost.

This month's Top Ten Tips were supplied by Tristan Jones, Technical Marketing Engineer at National Instruments UK & Ireland. To find out more about NI, measurements and LabView, log on to ni.com and ni.com/LabVIEW
If you want to send us your top five or ten tips on any engineering and design subject, please write to the Editor at EWeditor@nexusmedia.com.

The Collaboration of Industry Leaders

Mark Bowles, Founder and VP of New Business Development at Staccato Communications, praises inter-industry collaboration on new standards

As Apple Computer CEO Steve Jobs said, "Innovation distinguishes between a leader and a follower". It is that spirit of innovation and collaboration that explains how Certified Wireless USB moved from the engineering lab to commercialisation so quickly and why this technology is both widely supported and highly regarded. The past three years witnessed the hard work of industry leaders who were determined to lay the best foundations for the most valuable wireless personal network applications across the globe.

The leaders and innovators of all facets of the personal computing (PC), consumer electronics (CE) and digital mobile industries, along with new venture-backed companies, came together in early 2003. That's when we began developing standards for the personal network technology that would offer the highest data rates and the most consumer benefits, called Certified Wireless USB.

The early work began within IEEE as Task Group 802.15.3, which evolved into 802.15.3a. The interest in 802.15.3a was so great that 26 proposals were submitted by a wide range of organisations to become the standard specification. In just three months, the best features of 17 proposals were consolidated into a specification authored by Texas Instruments – called the MultiBand-OFDM proposal. This proposal was supported by almost all of the major semiconductor, PC and CE companies, as well as VC-backed start-ups. A small number of mostly second-tier companies supported an alternative specification, based on impulse radio technology.

The first MultiBand-OFDM specification was soon supported by an alliance known as the MultiBand OFDM Alliance (MBOA), which later became the WiMedia Alliance, while the alternative specification based on impulse radio was supported by the newly formed UWB Forum.

> **"Had the balloting been conducted based on a company count, the MBOA/WiMedia supported standard would have easily achieved the 75% threshold needed to establish a standard"**

It soon became clear that the efforts to create a single standard within the IEEE were becoming highly politicised and could become deadlocked. Had the balloting been conducted based on a company count, the MBOA/WiMedia supported standard would have easily achieved the 75% threshold needed to establish a standard. Rather than get trapped in that political maze created by the IEEE's protocol of individual voting, the leaders of Certified Wireless USB – fully aware that a number of important standards have been developed outside of IEEE – decided to do just that.

The momentum behind the MBOA/WiMedia-backed proposal accelerated when it was quickly endorsed by the USB Implementers' Forum (USB-IF). The USB-IF is the standards organisation also responsible for the wired USB standard, which shipped over one billion units in the past 12 months and continues to grow rapidly. The USB-IF selection of the WiMedia/MBOA specification has served as the foundation for the new Certified Wireless USB.

This progress is all the more remarkable when you keep in mind that the MBOA/WiMedia leadership continued its dedication to the standards development efforts within IEEE, until that process was completely exhausted in early 2006. Displaying a tremendous determination to serve this emerging industry, the MBOA/WiMedia leadership began seeking an alternative and parallel path to international standards starting two years earlier in late 2004. Those efforts have already yielded international standards for WiMedia specifications by Ecma International, an industry association founded in 1961, dedicated to the standardisation of information and communication systems, and ETSI (European Telecommunciations Standards Institute). WiMedia is now seeking official adoption of its specifications by ISO, expected in late 2006. This is a rare example of strong industry leadership that made possible broad endorsement and acceptance of a single wireless standard by the industry and international standards community.

So, whether you mark the progress of Certified Wireless USB from the four short years since FCC regulations first allowed the use of UWB technology and spectrum, or just three years since the standards development efforts began in earnest, the companies who have worked to create MBOA, the WiMedia Alliance and Certified Wireless USB can be proud of their long list of accomplishments achieved in record time. To those who speculate that it will take many more years to bring Wireless USB products to market, or worse, that consumers will have to choose between two conflicting standards, we say, "Keep your eye on the leader, Certified Wireless USB".

The Future's BRIGHT.....

Does the future hold great promises for copper posts; ask Keith Gurnett and Tom Adams

A microprocessor designed as a flip-chip and having, say, 6,000 solder bump interconnects is no novelty today, but it represents a stunning advance from the technological state of flip-chips of only ten years ago, when a few hundred solder bumps was an impressive achievement.

The trouble with solder bumps is that they are, in a sense, self-limiting. During reflow each solder bump assumes an essentially spherical shape. After cooling, it is a somewhat flattened sphere. The offset between the substrate and the chip face becomes even smaller as the diameters of solder bumps continue to shrink. At some point, the reduction in headroom makes underfilling of the chip a difficult proposition.

Solder bumps thus reach a minimum diameter – probably around 60 microns – beyond which further reductions in the x and y dimensions become very difficult. The reduced height of smaller solder balls may also be more susceptible to CTE (coefficient of thermal expansion) mismatches.

How to break through the limitations of solder bumps? In many applications, the answer will be copper posts. Copper post technology is not yet widely known, but it is being developed at many locations around the globe, and one of the major assembly houses plans to offer copper posts to its customers next year. Will the copper posts be more expensive than solder bumps? In the beginning, they will – just as early flip-chips – be more expensive than wire bonds.

But look at the advantages that copper posts offer over solder bumps:

- They can achieve a much higher I/O density. Copper posts under development today can put about four times as many I/Os in a given area as can be achieved with solder bumps, and the potential is there to make copper posts much smaller than this.

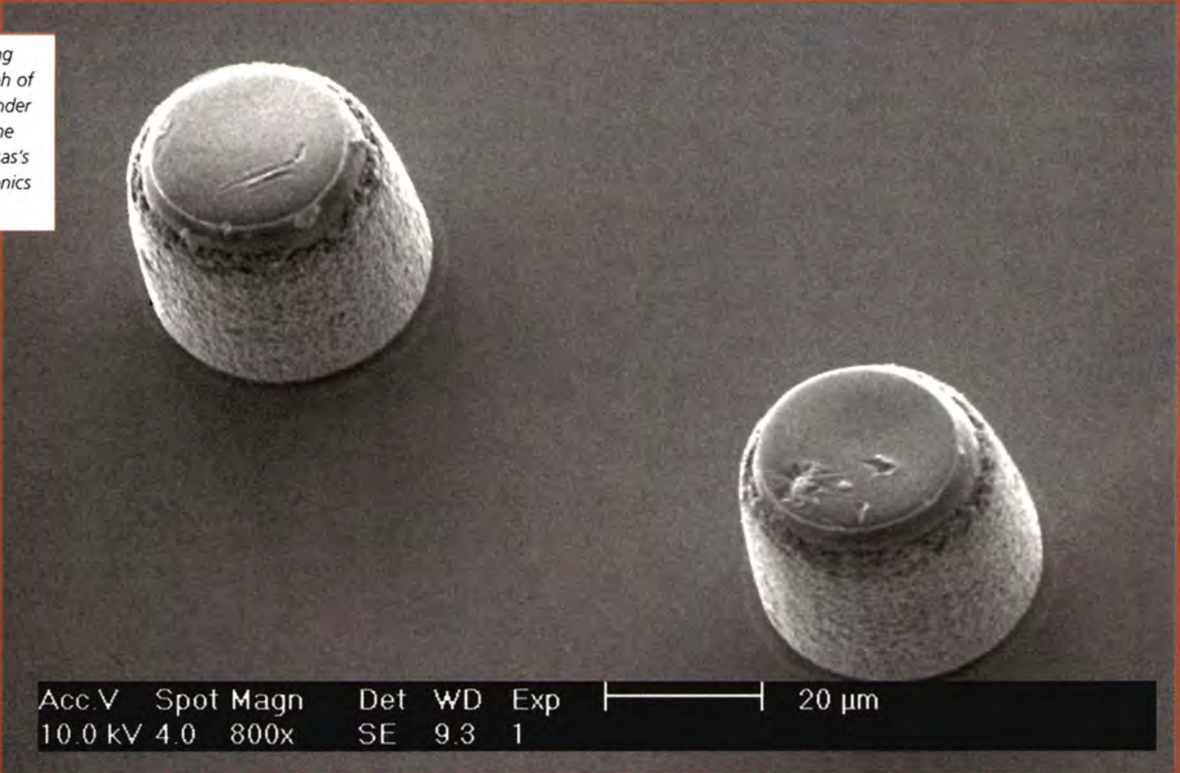


Figure 1: *Scanning electronic micrograph of two copper posts under development at the University of Arkansas's High Density Electronics Center (HIDEC)*

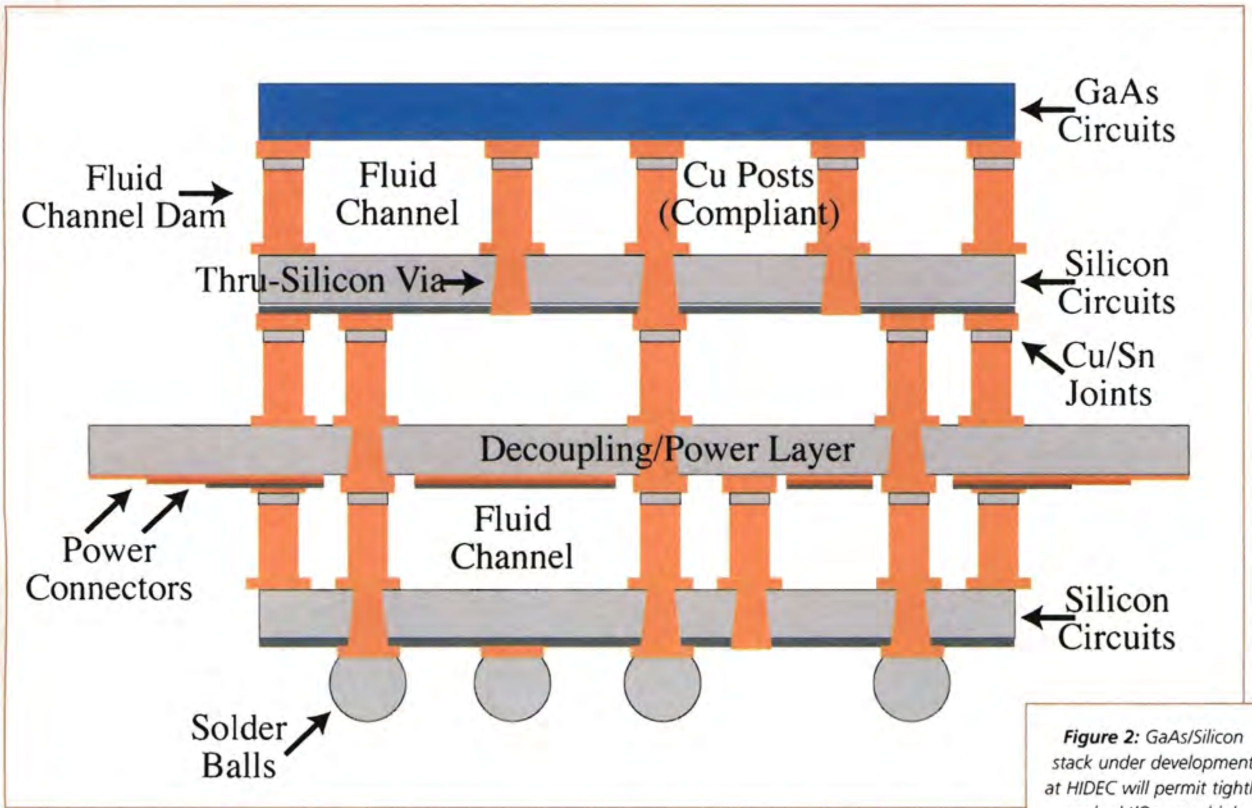


Figure 2: *GaAs/Silicon stack under development at HIDEC will permit tightly packed I/Os, very high speed and a high level of compliance*

- Because they are relatively tall and slightly flexible, copper posts can accommodate coefficient of thermal expansion mismatches that would cause solder balls to crack. Lead-free solder balls are probably more susceptible to cracking than conventional tin-lead solder balls.
- Since they are taller than solder bumps, the copper posts tend to make the underfill process less demanding. The diameter of a copper post is not directly related to its height, as is the case with solder bumps.
- Copper is much more efficient than solder at removing heat from the chip.
- Copper bonds to a substrate more firmly than either type of solder, so disbonds are less likely.

One focus of copper post development is at the University of Arkansas in the US, where Dr Leonard Schaper leads a team that is developing a prototype package for the US Air Force. The package is intended for an advanced radar system, and is intended to collect vast amounts of data and to process that data into a usable form – both key requirements for critical radar applications.

What Dr Schaper and his team are developing is a stack of four thinned die. The top die is a gallium arsenide receiver, below which are three silicon die to accomplish the processing of the received data. All four die have plated vias and are interconnected by copper posts rather than by solder balls or wires. The copper posts are 30 to 40 microns in diameter and from 80 to 100 microns tall. If the die are thinned to 50 microns and if the post are 100 microns tall (somewhat better than 80 microns as they are more compliant), then the whole package will have a thickness on the order of 0.5mm.

Along with the copper posts, the plated vias are a key element and give performance and speed far great than can be achieved with wire bonds, because the vias have the reduced capacitive and inductive parasitic effects. The development of copper post technology makes possible what designers like to call 3D integration, meaning that in addition to shrinking package and board sizes in the x and y dimensions, they are shrunk in the z dimension as well. The conventional stacked-chip package – which entered

......The Future's **COPPER**

production only a few years ago – depends on stacking chips, separating them with epoxy and using wire bonds as interconnects.

In a conventional stack, "you're not really electrically interconnecting the chips," notes Dr Schaper, "you're basically bringing them to a substrate and out to the outside world". The key is to avoid long wires and keep all interconnects as short as possible. When fully exploited, the avoidance-of-long-wires approach may turn out to a very inexpensive production method, thinks Dr Schaper.

> *People are thinking about algorithms where you'd be able to access all the data from adjacent pixels at every level in your pipeline, because it's right there adjacent to you. That's one thing you can do in 3D electronics that you can't possibly do in 2D electronics.* – Dr Leonard Schaper, *University of Arkansas, the US*

"A bunch of years ago when I was at Bell Labs, we demonstrated that the real driver for cost in electronic systems is the length of wire. And if you can minimise the length of wire in a system, you're going to minimise the cost. So, if I take a system that is now spread out all over a circuit board and I condense it into a 3D stack, I've reduced the wire length dramatically. Not only do I reduce the latency or the delay, but I also think in the long run, once these are mature processes not just the first experimental ones. Once I have far less wire in my system, I might have far less cost."

The copper posts are currently 80 microns tall. By late 2006, when a working prototype package will be assembled, Dr Schaper expects to be able to grow posts that are 100 microns tall. On the top of the post is a small dab of solder to provide better bonding with the bond pad on the face of the chip. The body of the post is typically encased in epoxy, polyimide, or another underfill material.

However, wafers and the through-chip vias come before the posts. "You create the wafer first," Dr Schaper says. "You put the connection points on the top and bottom, then you dice it and take parts from maybe several different wafers and then you assemble them vertically as a chip stack, as a multi-layer wedding cake."

His preferred joining technology is a copper-tin alloy. Copper-tin is a wonderful eutectic that once it forms, its melting point is about 200°C higher than its formation point. So, if I've got two chips and I want to join them together, I do it with copper-tin and, then, the next chip that I want to put on top of that, the bonding on the first two doesn't melt again – unlike solder, which would completely melt again."

One of the problems with a multi-chip stack is the amount of heat that needs to be dissipated. The copper posts themselves are good pathways for heat removal, but they are passive. But Dr Schaper has used the posts to create horizontal channels between each of the layers in the stack. Through these channels he pumps a Freon-like coolant. "We're looking at posts that are 30 microns in diameter and 100 microns high," he explains, "and that little fluid channel that you create, 100 microns high, we should easily be able to get 100 watts per chip out of the thing. And probably more – that's the first conservative estimate."

What is remarkable is the degree to which the design and functionality of the mixed chip types, through-vias and copper posts work together: the through-vias make it possible to use copper posts and the posts permit compliance, I/O density and two forms of thermal control.

Are there applications for this type of 3D integration outside of the military? Dr Schaper thinks there are. Military systems often involve processing visual, sound, IR or radar data. One of the things that matter is the spatial relationship among the pixels. "If you process this using a two-dimensional system, like 2D regular conventional silicon laid out on circuit boards, you lose the spatial relationship among the pixels – they're not next to each other any more," he says.

"But in 3D we don't have to do that. People are thinking about algorithms where you'd be able to access all the data from adjacent pixels at every level in your pipeline, because it's right there adjacent to you. That's one thing you can do in 3D electronics that you can't possibly do in 2D electronics."

In general-purpose computing, successfully applied 3D electronics could bring a revolution. "I can bring something like my main memory a whole lot closer to my processor chip than I can if I'm on conventional printed wiring board technology. And I could do it with a very large bandwidth, because now, instead of a 64-bit data bus coming off of a packaged device and going through the board to a bunch of memory modules, I can have extremely dense z-axis connections up to the memory. Maybe it's 500 bits wide or 1,000 bits wide. The capability when you start talking about z-axis connections on 20-micron to 50-micron pitch is just huge. So, I can get a very large memory bus width at almost no cost," added Dr Schaper.

At the very least, this is an elegant way to put an end to discussions of leaded vs lead-free solders.

LI-ION BATTERIES for High-Tech Applications

Do you need to design a portable device or heavy-duty industrial equipment? No problem, says Michel Broussely from the Specialty Battery Group of Saft in Poitiers, France – you can use Li-ion batteries as they possess the best characteristics yet

The term "Li-ion batteries" actually encompasses a whole family of batteries using various active materials to build electrochemical systems that are used or being studied for many different developments.

Li-ion can be considered as a revolution in the battery technology. Such batteries were introduced at the beginning of the 90s; the first of non-aqueous rechargeable systems to be manufactured on the large scale. They are now widely used in most of the portable systems such as mobile phones, laptop computers, camcorders and digital cameras, where they have progressively replaced NiCd and NiMH batteries within the last five years.

This type of battery can be also used for industrial applica-tions as well as aerospace, military, electric vehicles/hybrid electric vehicles (EV/HEV) and telecom applications, providing that the selection of active materials is able to bring a long life, either on the cycling or storage side.

Although recent, this battery concept is the result of decades of research on lithium batteries. A decisive step was reached when carbon was proposed as the insertion structure to replace the lithium metal electrode, where the bad cycling efficiency in non-aqueous electrolytes has never been satisfactorily improved.

Main Features

The main general feature of Li-ion batteries is their remarkably high specific-energy and high energy density, surpassing all existing systems. Using highly energetic materials, lithium on negative and high oxidation state metal ions on positive, produces a high unit cell voltage, in the range of 3-4V (mostly depending on the nature of the positive electrode chosen), i.e. more than twice the conventional aqueous systems. This has two strong benefits: one, use of a single cell in such applications for which 3V minimum is required (example: portable phone) and, two, less cells are needed to build a high voltage battery versus the case in large batteries, for example about 300V for an EV.

Another feature is that Li-ion electrochemistry can be also used to build very high power batteries. This is a paradoxical property for a non-aqueous battery, using organic electrolyte of generally low conductivity. It is made possible because the electrolyte does not contribute to the electrochemical reactions and side reactions creating self-discharge are extremely reduced. Very thin separators and electrodes can therefore be used, allowing a large working surface area.

A general comparison of different battery systems in a pseudo-Ragone plot of W/kg versus Wh/kg is displayed in **Figure 1**.

Materials

The most common electrochemistry used today is the $LiCoO_2$/graphite system in small portable applications, where it will still exist for a long time. Its main drawback is the high – and variable – cost of cobalt, which makes it inappropriate for most of industrial large batteries applications. Other chemistries are either commercialised in smaller volumes or being developed, mainly differing in the nature of the positive materials used:

- $LiMn_2O_4$ and derived materials have lower expected cost, but suffer from short life due to slight solubility of manganese that destroy the negative electrode's long-term stability, especially at high temperatures.
- $LiNi_xM_yO_2$ materials, where M can be several metal ions, so-called Ni-based. Having a similar structure to that of $LiCoO_2$, these materials have lower cost potential because they use less cobalt. One of

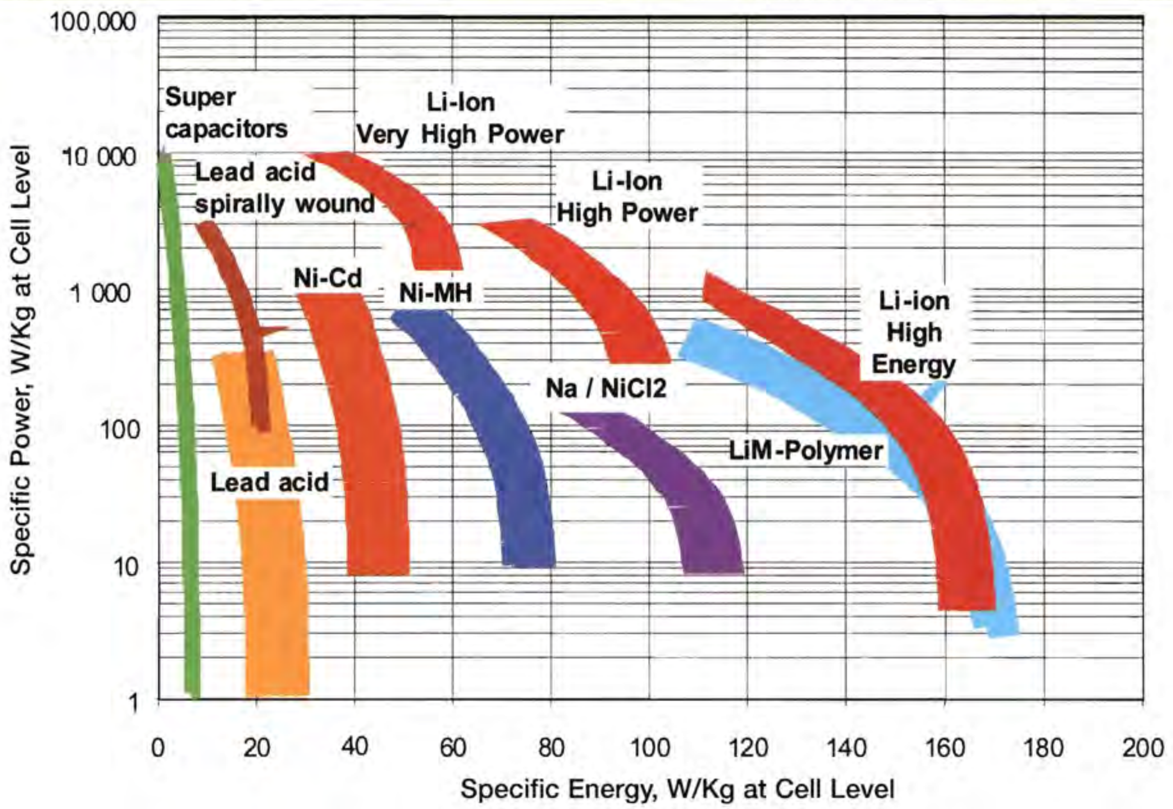


Figure 1: *General comparison of main rechargeable systems used in industrial batteries. Pseudo-Ragone diagram W/kg / Wh/kg*

them, LiNixCoyAlzO2, also called NCA, has been studied and commercialised by Saft in industrial batteries. It exhibits excellent cycling and life duration properties – the best figures that Li-ion chemistries can show today.

Nickel/Cobalt/Manganese oxides – NMC – are also studied, with the aim of replacing LiCoO2 at lower cost.

- LiFePO4 has been more recently introduced. Its main feature is an improved stability on overcharge, improved safety and a potentially attractive low cost due to the iron. Energy density is, however, significantly reduced and it may be suitable for high power applications rather than high energy ones.

The negative active material consists of carbon powder in which lithium ions are inserted during charge, together with the corresponding number of electrons. Initial carbon material when Li-ion was introduced was a disordered carbon (hard carbon), still used in some cases. Most of Li-ion batteries now use higher capacity density and lower voltage graphitised carbons.

Most of the electrochemical systems (except the one based on LiFePO4/graphite) exhibit a continuous variation of voltage, decreasing as a function of state of charge (SOC). This is a very interesting feature for two reasons: one, easy SOC indication and, two, self-balancing of cells in parallel, making possible the straight parallel association to provide the required capacity from single unit cells. An example of voltage profile is given in **Figure 2**. This is a very important property for building high capacity batteries, with cells in parallel that should be maintained at the same SOC, insuring good distribution of current density, which is paramount for long life.

The Technology At Heart

The heart of Li-ion technology, as in many other battery systems, is the electrode technology and process. The electrode manufacturing processes consist of coating thin metallic foils (Al for positive and Cu for negative charge) with a mixture containing the active material, an electronic conductor (for the positive mix) and a binder dissolved in an appropriate solvent (generally PVDF/NMP). After drying, this coating is reduced to the desired thickness/density. The electrode thickness depends on the maximum power required. This is a very interesting feature of Li-ion battery technology, as it allows a wide range of power/energy ratio designs through the same basic electrode manufacturing process. Appropriate current collection and tabbing, cell shape and design are, however, necessary.

Because of the high reducing character of lithium, which gives the high energy density of the battery, the electrolyte cannot be based on a water solvent. It consists of a solution of lithium salt and LiPF6, dissolved in organic solvents. Although not participating directly in the electrochemical oxidation-reduction reactions during use, the electrolyte is not neutral versus electrode reactivity. It forms, at least on the negative electrode, a passive layer that efficiently protects against inserted lithium corrosion and gives the system its chemical stability. The nature of this layer, also called Solid Electrolyte Interface (SEI), is present in a lithium battery of any kind and is the key to the Li-ion battery's long life, cycling and storage. Additives to the solvents have been extensively studied to improve the property of this layer. Among them Vinylene Carbonate (VC) has been found as the most effective.

Separators, all in the form of thin (25µm or less)

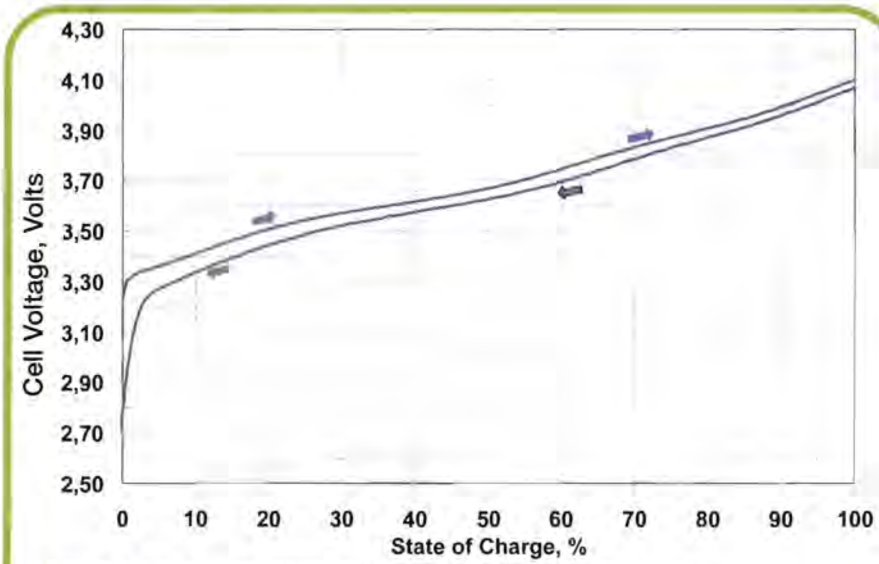


Figure 2: *Typical Li-ion voltage profile (LiNixCoyAlzO2/graphite system). Charge/discharge curves at low rate*

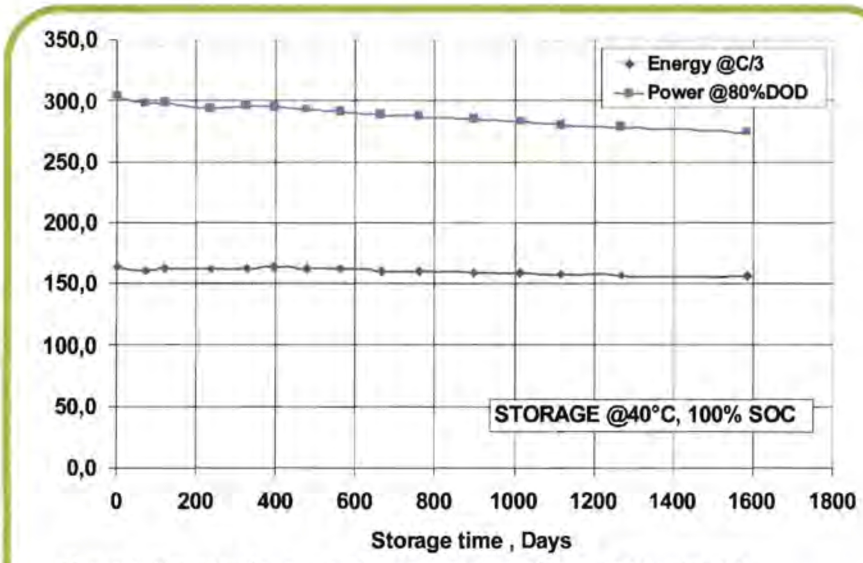


Figure 3: *Example of energy and power retention of large 45Ah Li-ion cells VLE45 during extended high temperature storage at full state-of-charge*

microporous membranes, may be either in polypropylene or polyethylene, already used a long time in primary high-rate lithium batteries.

Ultimately, there is no difference between the technology implemented in small portable Li-ion cells and large "industrial" cells. In most cases, the cell stack is built by rolling the electrodes in spiral, as with the case of small cells. Because of their small thickness, this is the most efficient way for assembling electrodes, compared to planar conventional stacking. The coil may be cylindrical, or flattened to make a prismatic-shaped cell. Both designs have their own advantages and drawbacks, but are currently being produced.

Better volume filling in battery assembly is obtained with prismatic cells, which, on the other hand, are more sensitive to bulging on cycling or aging. The stronger mechanical characteristics of cylindrical cans give the cell better dimensional stability and homogeneous pressure within the electrode stack. The usual cell range proposed by battery manufacturers is from 3Ah (high power design) to 100Ah (high energy design).

Battery Assembly and Monitoring Systems

A significant difference from conventional aqueous batteries for the user is the absence of electrolyte participation to electrochemical reaction as water does, notably at the end of charge or overcharge. That necessitates an accurate end-of-charge monitoring to prevent overcharge, which would destroy the electrochemical properties of the materials and, if carried on too deeply, would produce overheat and create safety issue.

Fortunately, overcharge is always synonymous with over-voltage, which makes the monitoring easy by voltage control. Monitoring through electronic circuits is, therefore, mandatory as soon as several cells are assembled in series to constitute a battery system.

Other main functions of the Battery Management System (BMS) are the SOC indication and monitoring, and capacity equilibration between cells as necessary over battery life ("balancing"). When cell rest voltage (OCV) depends on SOC, these functions can be easily treated. That is not the case when the OCV remains constant whatever the SOC, as in the case with the $LiFePO_4$/graphite electrochemistry.

Although such a BMS is always necessary, even with aqueous systems, using Li-ion cells makes it more complicated and it contributes to the total cost of this technology. On the other hand, these systems allow better control of complex battery assemblies, easier monitoring, diagnostics, state of health knowledge, state of charge, etc – all parameters that can be transferred to the monitoring system of the application.

Because electrolyte recombination or consumption is not involved as in aqueous systems, the energy recovery on cycling is much better, 100% of electricity put in is recovered, the energy loss being only due to the polarisation effect. This is a very attractive property for any application where saving energy is primary, i.e. most of the industrial applications, for example satellites, solar energy storage or HEVs. Beside the energy saving, less heat is produced on charge, allowing a simpler heat exchange system to

Cells		VL 45 E	VL 41 M	VL 27 M
Nominal Voltage	V	3.55	3.55	3.55
Rated Capacity at C/3	Ah	45	41	27
Typical Power	W	710	850	760
Dimensions	mm	54 / 222	54 / 222	54 / 163
Typical Weight	kg	1.07	1.07	0.77
Specific Energy	Wh/kg	150	135	130
Energy Density	Wh/dm^3	310	285	275

Table 1: *Main characteristics of Saft's high-energy, industrial, Li-ion cells*

Cell	VL30P	VL20P	VL7P	VL8V	VL4V
Capacity (Ah)	30	20	7	8.6	4.4
Max cont. current (A)	300	250	100	520	260
Peak current (A) 500	500	250			
Energy (Wh) at C/3	107	71	25	30	16
Power (W)	1250	1130	670	1880	1150
Diameter (mm)	54	54	41	41	34
Length (mm)	222	163	145	152	152
Weight (kg)	1.1	0.80	0.37	0.47	0.32

Table 2: *Main characteristics of Saft's high-power, industrial, Li-ion cells*

Model	Thickness (mm)	Width (mm)	Height (mm)	Weight (g)	Nominal Capacity (Ah)
MP 144350	13.8	43	50	70	2.7
MP 174865	18.0	48	65	120	5.3
MP 176065	18.0	60	65	155	6.8

Operating Conditions	
Discharge	Charge
up to 2C	C max
-50 to +60°C	-20 to
cut off 2.5 V	+60°C
	4.20 V

Table 3: *Main characteristics of Saft's medium, prismatic, Li-ion cells*

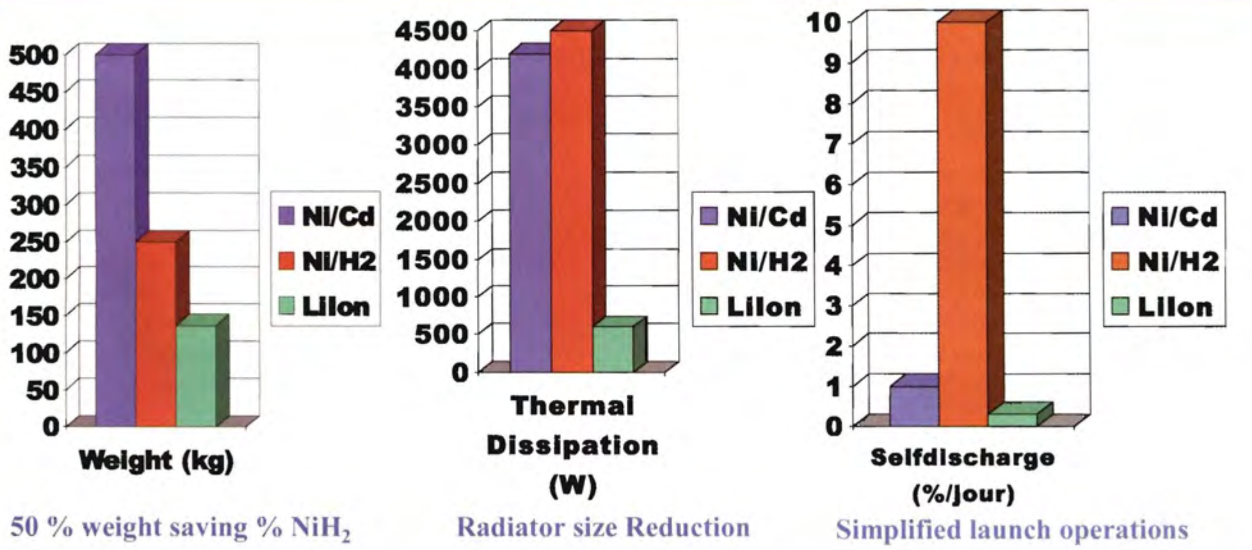


Figure 4: *Performance comparison of the three satellite battery technologies (for 8kW satellite power)*

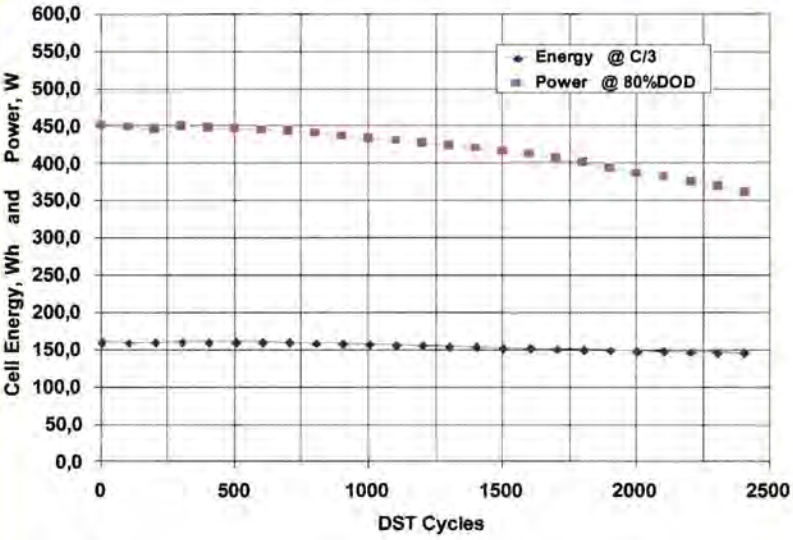


Figure 5: Energy and power evolution of Saft "VL45E" cells during cycling at 80% DOD DST cycle. Every 50 cycles, energy measured at 100% DOD – C/3, power measured at 80% DOD, 300A – 5mm pulse

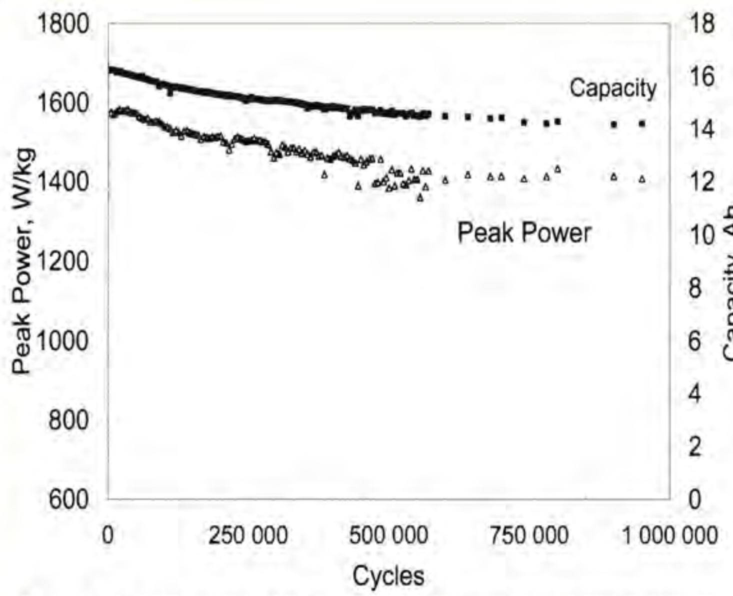


Figure 6: Shallow cycling of high power cell under HEV load profile (periodic 100% DOD diagnostic)

control temperature. Air or liquid cooling can be used, depending on the choice of the application designer.

Assembling cells to make large batteries generally consists of making first modules of several cells connected in series or parallel, these modules being then assembled in batteries, to reach the size required by the customer.

Application Examples

Long life is an extremely important feature for battery systems used in applications requiring no maintenance and high reliability. The electrochemical system chosen by Saft exhibits outstanding cycling and aging on storage performances. As an example, **Figure 3** describes the energy and power retention of cells over an extended storage period of about five years, at elevated (40°C) temperature, at full state of charge. This makes them particularly suitable for use as power sources in spacecrafts, in which they have already now demonstrated a full ability of powering satellites in space.

Figure 4 compares the main characteristics of the Li-ion batteries with the battery systems typically used in satellites today. With the lower weight, the best cycling efficiencies are the features which make them very attractive for this application.

The large number of cycles, either with complete or partial discharge, as shown in **Figure 5** and **6** for 80% and 2.5% DOD cycling respectively, is also a key parameter for space applications and electric and hybrid cars. In this later application, it is anticipated that Li-ion will replace the NiMH presently used, thanks to its outstanding higher power density (typically about 3kW/kg) and anticipated lower cost in large volumes.

Examples of space or EV battery assemblies are described on **Figures 7** and **8**.

In the military field, beside many specialised high-energy or high-power Li-ion batteries for specific equipment, a light portable rechargeable power sources is of major importance to provide energy to the soldiers' increasingly sophisticated equipment. Small prismatic Li-ion cell of superior performances are assembled in batteries to provide the required compact and light batteries to specifications, able to work in a wide temperature range. **Figure 9** describes the discharge profile of such cell at -40°C. General characteristics are described in **Table 3**.

Power Source Of Choice

Li-ion electrochemistry has now demonstrated its ability to be used in large batteries for a very wide range of applications. The main features of these power sources are high energy or high power, extended cycling ability, long life and high reliability. Their superiority has already been proven in various

Figure 7: Example of a 25kWh battery for EV

applications through extended prototype testing such as in EVs, for example.

The space industry, where Li-ion brings very substantial benefits, has already adopted and qualified this technology. Li-ion batteries are already beginning to replace existing Ni/H2 batteries. There is no doubt that this system will very soon find its place in the industrial battery market. Further cost reductions in battery technologies will open the road to different market segments, such as automotive for example, where HEVs are offering the biggest stakes. Material costs and associated electronics represent the major part of the present costs and should significantly decrease with increasing production level.

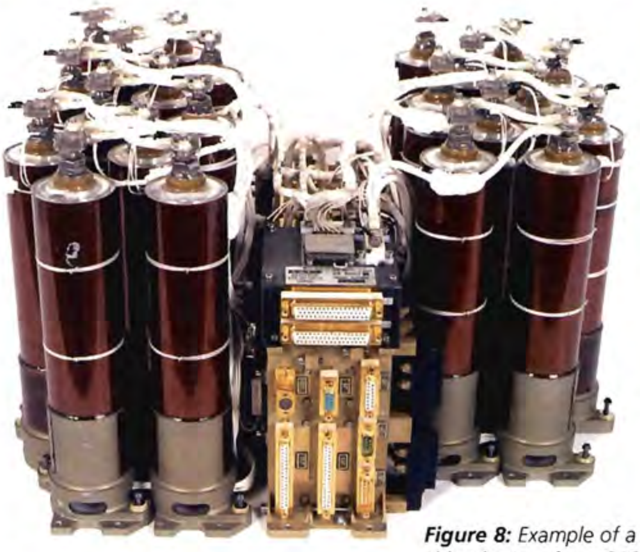


Figure 8: Example of a Li-ion battery for a GEO satellite

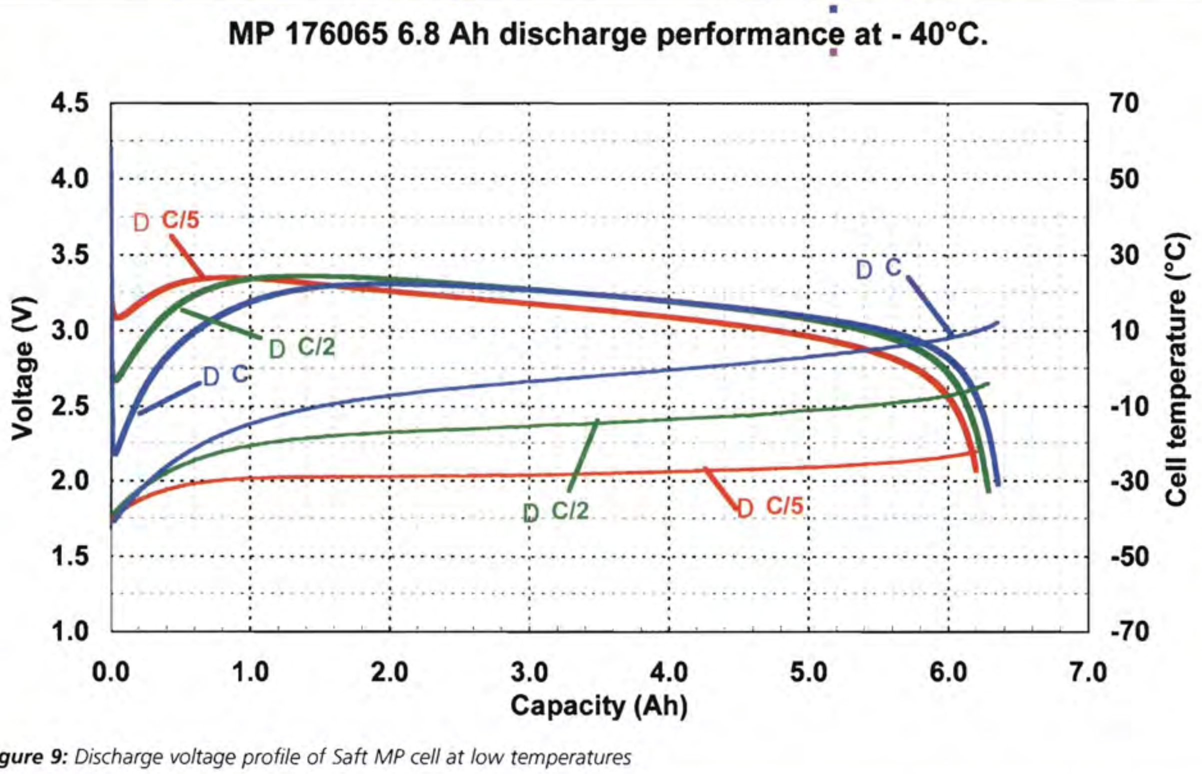


Figure 9: Discharge voltage profile of Saft MP cell at low temperatures

Comprehensive monitoring of standby batteries

Nigel Scott, technical and business development manager at LEM, describes new approaches that enable standby battery systems to be continuously monitored during their service life, offering the capability to detect potential failures before they happen

Over the last 30 years, the standby battery industry has become dominated by the Valve Regulated Lead-Acid (VRLA) battery, with its cousin the gel. These high-capacity sealed cells are used to support a wide variety of critical systems. The batteries are held on a small continuous float charge and this affects the failure modes of the cell.

Although based on slightly different chemistries, the characteristics of the VRLA – sometimes called the Sealed Lead Acid (SLA) or Activated Glass Mat (AGM) – and the gel battery have similarities, the main one being that they are both much more sensitive to temperature and charging conditions than their predecessor, the liquid electrolyte or 'flooded' cell.

Most VRLA batteries are charged at a fixed voltage of exactly 2.27V per cell. Overvoltage during charging, more than 2.3V per cell for example, will cause the electrolyte in the glass pads to produce more gas than the recombination chemistry can cope with and, over time, this will escape through the valve and be lost.

Temperature also plays a part. These cells are designed to last for up to 12 years. However, even if the charging voltage is correct, if the ambient temperature is too high -25°C+ in the EU, 30°C in the US – the cell will overcharge and moisture will again be lost.

Other problems can be failure modes such as early sulphation, poor connection between the posts and the grids, poor connection between the grids and the plates, stratification of electrolyte and accelerated grid corrosion.

If a cell anywhere in one of these batteries becomes open circuit (for example when the electrolyte dries out), then the battery cannot supply any current. If a few cells go short circuit (usually due to manufacturing faults), it is not as critical as an open circuit in the short term. However, the remaining cells in the battery are then being overcharged.

Spectacular Failures Avoided

One of the most spectacular failure modes is thermal runaway, which is peculiar to VRLA and gel batteries. This is a positive feedback reaction, in which the higher float charge current tends, over time, to increase the temperature in the cell. This, in turn, causes the cell to take more float current and the process accelerates, resulting in fire or explosion. It is not common, but happens more often than is generally recognised. The only way to detect it is to monitor the internal cell temperature.

The traditional method of measuring the specific gravity of the electrolyte to estimate the capacity of each cell is not possible with VRLA or gel technology and the only certain method of determining to what extent the battery is capable of supporting its critical load has been by autonomy (discharge) testing the battery as a whole. Most installations have to be shut down during testing to avoid possible damage to their loads, and this can cause problems for the services they supply.

To avoid the high cost and disruption of these tests, non-intrusive electronic methods of continuous monitoring have been developed to determine in-service capacity. These systems aim to provide enough information about the battery to detect any incipient failures before they happen, hopefully extending the service life of the battery, as well as preventing catastrophic failure during a power outage.

Today, the battery system parameter most commonly monitored is the terminal voltage of each cell or monobloc (a monobloc is two or more cells in the same case); although several manufacturers now monitor cell internal impedance as well, with varying degrees of success. In addition, even the most basic monitoring systems monitor battery charge/discharge current and ambient temperature.

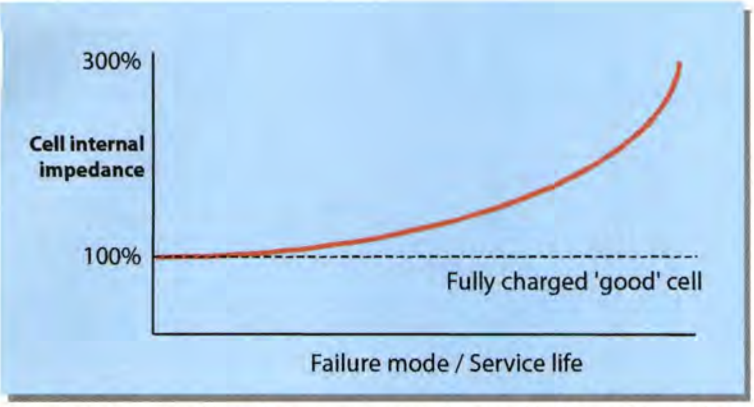


Figure 1 *Cell internal impedance is not necessarily a good indicator of impending failure. It is not easy to detect the early stages of failure by this method*

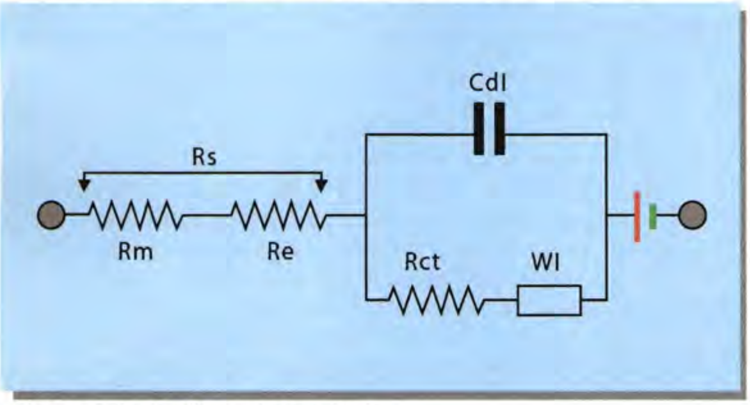


Figure 2: *The Randles equivalent circuit for an electrochemical cell*

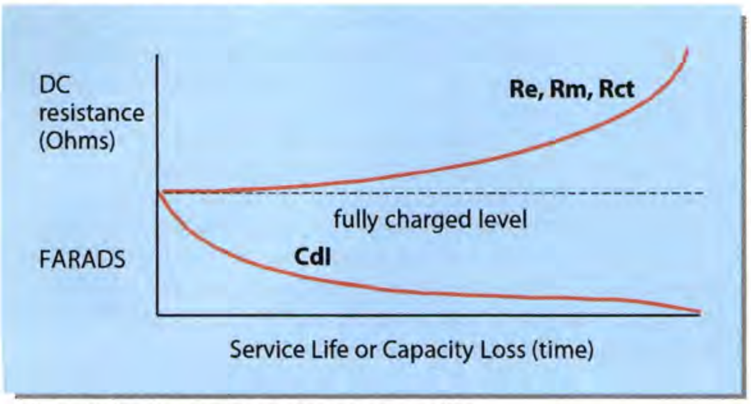


Figure 3: *Randles parameter progression over the cell lifetime or discharge*

Heading Forth Intelligently

Continuous battery monitoring is fast becoming generally recognised for its importance in lowering maintenance costs and helping to prevent catastrophic battery failure. What has been lacking is a high quality product at a cost low enough for the average battery user.

Now, however, LEM has moved from purely analogue-based transducers into the area of intelligent components. Its Sentinel module is based on the system-on-chip (SoC) approach, jointly designed by LEM and an integrated circuit (IC) maker. This is embedded in a module capable of measuring cell and monobloc terminal voltage, internal cell temperature and internal impedance, at a cost affordable by most battery system users.

Cell voltage is seen as the least important parameter, since the charger voltage dictates the overall voltage, and cells only deviate greatly from their individual nominal voltages when in the final stages of failure – probably too late to prevent a failure of the battery. Cell voltage monitoring is, therefore, of most use during a discharge due to a mains outage, or a discharge test, so that cells that are failing to meet specification can be detected and changed out.

Cell temperature can, on the other hand, be significant, since thermal runaway is a logarithmic progression and can normally be detected in advance of occurrence by trending the individual cell temperatures. Cell 'simple' (ACV/I) impedance is another significant parameter, which also tends towards a logarithmic progression (see **Figure 1**).

A failing cell can be 150-200% of its original 'new' value, while a completely exhausted cell is likely to be over 300% of the original value. There is no direct relationship between impedance/ conductance/resistance and performance or end-of-life. However, trending the impedance value over time gives a good indication of possible failure and can certainly indicate cells that require further attention. All three are virtually identical in character and are promoted by different product manufacturers, depending on their products; conductance is, of course, the inverse of impedance/ resistance.

Impedance monitoring has not been the perfect solution to problem detection that it was hoped to be and some systems are seen as being inconsistent in failure detection. Recognising this, LEM has spent a great deal of time investigating the

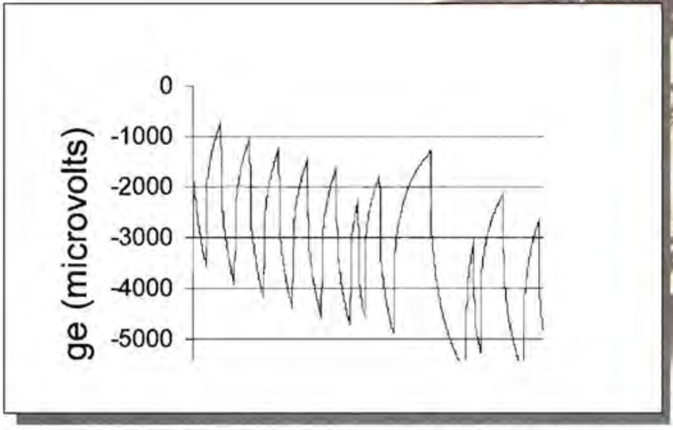


Figure 4a: *A typical voltage 'micro discharge' characteristic for a current 'shorting only' random pulse pattern*

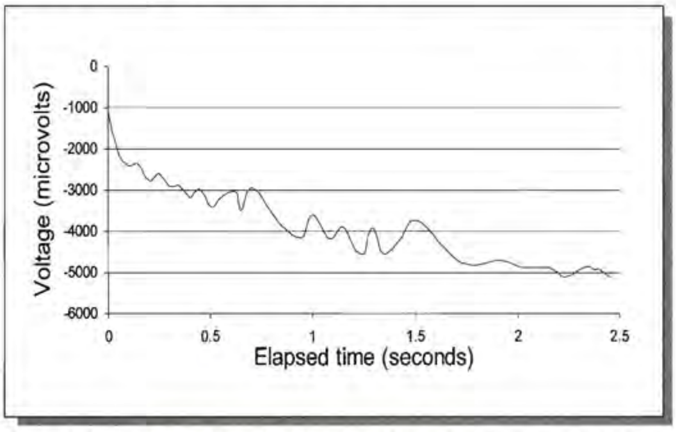


Figure 4b: *Underlying trend (splined), with local divergences, for the Figure 4a voltage response to a current-controlled PRBS*

reasons for the fallibility of measurement versus failure detection and has developed an extremely dependable test method, which penetrates well into the cell's energy layer, to ensure the highest possible degree of reliability.

It can be seen from Figure 1, however, that detection of a failure mode in its early stages is not easily achieved and a problem may not be detected until the cell performance is significantly degraded. It would be of great benefit if the next generation of continuous standby battery monitors could give more information much earlier in the deterioration of the cell, whether due to a failure mode or natural causes.

New Module on the Block

To that end, LEM has been working on deriving more complex data from the cell or monobloc. The company has several patents in the area of cell parameter analysis, and the continuing developments will be incorporated into the next generation of cell interface module, designated 'Lifeguard'.

The system that LEM is developing is based on the well-established electrical principle that any complex electrical circuit under stimulus can be represented by a simple equivalent, which exhibits exactly the same response characteristics. An electrochemical cell can be represented by such an equivalent circuit and **Figure 2** illustrates the standard circuit, known in the UK as the Randles equivalent circuit. There are more complex models, however the Randles circuit is more than adequate for the determination of first order parameters, such as capacity and condition or state of health.

The Lifeguard system injects a complex test signal through the cell under test. The current waveform and the resultant voltage response are then recorded and post-processed using custom designed algorithms, to determine the Randles parameters.

- **The Metallic Resistance (Rm)**: represents the resistance not only of the metal itself, posts, bus bars, grids and plates (paste), but the efficacy of the jointing between them.
- **The Electrolyte Resistance (Re)**: Electrolyte loss can be one of the main causes of premature cell failure.
- **The Double Layer Capacitance (Cdl)**: Is a function of the effective plate area and the dielectric strength of the electrolyte.
- **The Charge Transfer (Faradaic) Resistance (Rct)**: Is due to limitations in the rates of chemical reaction kinetics at the plate/electrolyte interface.
- **The Warburg Impedance (Wi):** Is representative of a diffusional mass transport process. It is however a low frequency component, not present during discharge.
- **A pure electrical generation element**, removed during the testing process.

The elements of the Randles circuit are representational of actual processes and/or failure modes experienced by the cell over its service life.

Figure 3 shows the progression of the parameters over the life of a cell. The same characteristics are also demonstrated during a discharge, or loss of (a/h) capacity. As in Figure 1, it can be seen that resistance (simple impedance may be considered as resistance, since at practical test frequencies the relative contribution of the RC network to the overall impedance is not significant) is not the prime factor during the early stages of failure or capacity loss. Impedance alone, therefore, does not give any

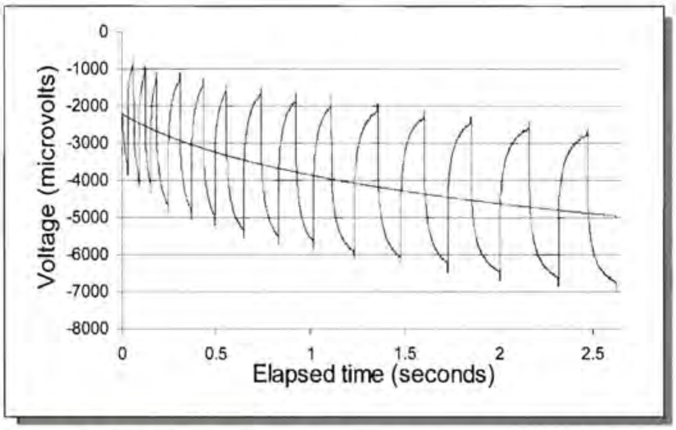


Figure 4c: *Pulse pattern design for a predictable underlying shift, with custom-modelled trend line*

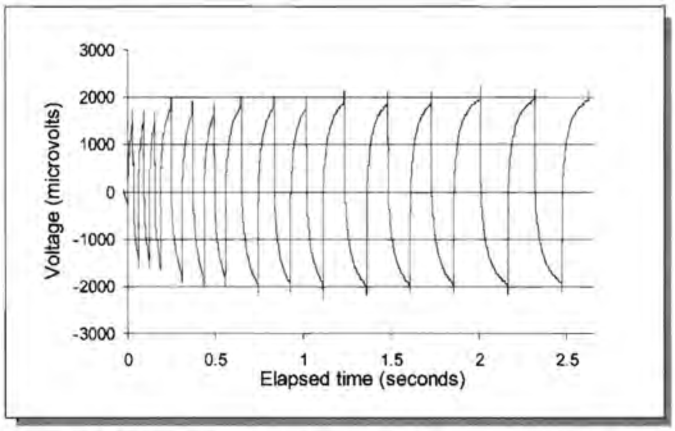


Figure 4d: *Voltage response with the underlying micro-discharge 'drift' removed*

significant indication until the capacity loss is greater than perhaps 25-30%.

Since the industry standard is to replace batteries that fall below 80% of specified performance, it is clear that possible failure must be indicated far earlier than at present.

Unlike resistance, double layer capacitance differs significantly in the early stages of all failure modes, except purely metallic corrosion (Rm). There is a much more direct and quantifiable relationship between the prime health indicator, capacitance (Cdl), and cell ampere-hours, and between the capacitance of 'healthy' and 'poor' cells of the same type, than there is between single value resistance and cell condition.

Monitoring Technique

In the early stages of development there were several problems to be overcome. The original algorithms were developed using a bipolar test signal. This was found not to be as reliable as unipolar test signals. However, on the switch to unipolar signals, one of the significant problems encountered was DC drift during the test.

LEM's Lifeguard system is integral to each cell and uses a unipolar Pseudo Random Binary Signal (PRBS) which draws current from the cell. This, however, will 'micro-discharge' the cell, the net effect of which will be reflected in the cell's voltage response to the test signal (see **Figure 4a**). The underlying 'DC' trend in this type of data set can be seen in **Figure 4b**.

This drift distorts the cell's transient discharge response, depending on the number of cells/bloc, ampere-hour rating, condition and state of charge. Effective low-pass analogue filtering is deleterious to the frequency ranges of interest, as they lie within the harmonic spectrum of the drift and are of the order of its fundamental. Simply removing the above trend does not preserve the characteristics of the data set necessary for correct parametric estimation. The underlying distortion must be removed in a way that will not distort the signal response.

By rearranging the varying frequency signal pulses in a frequency sweep, the cell voltage response can be made to follow a predetermined curve, e.g. logarithmic (**Figure 4c**).

Once the underlying drift curve becomes uniform, firmware algorithms can then be designed to model the drift and remove it, resulting in a mean zero voltage data-set, suitable for direct input to the Sentinel algorithms (**Figure 4d**). This method can reduce drift errors to less than 0.1%, without causing discernible distortion of the data-set. Algorithms can then be applied to the measured waveforms and the equivalent circuit parameters can then be derived with a high degree of accuracy.

Once the SoC can determine the cell's real condition, several valuable additional functions can be programmed:

- **Terminal Voltage Optimisation (TVO):** Due to variations in chemical constituents, the cells of a battery often have differing internal impedances. Since the charger fixes the terminal voltage of the battery as a whole, cells with higher impedances will manifest higher terminal voltages and the lower impedance cells will take less. Over time, this can cause problems. In cells with a higher terminal voltage, it is likely to lead to accelerated positive plate corrosion and electrolyte loss (dry-out). In lower voltage cells, it can cause accelerated sulphation.

With the SoC intelligent control system integral to the cell however, those cells exhibiting a higher than specified float terminal voltage can quickly be detected and a system to 'shunt' the float current around the cell devised, thus optimising the cell's terminal voltage.

However, float voltage optimisation can only be reliably carried out if the cell can be determined as being at maximum capacity without recourse to the terminal voltage, since this is controlled by the optimisation process. It may be that the cell actually requires a higher charge voltage to remain healthy and 'optimising' without the required data may damage the cell.

■ **Active Charge Management (ACM) for extended life:** Tests carried out by battery manufacturers have indicated that the float current in VRLA cells is higher than that of flooded for the same terminal voltage. One effect of this is to accelerate positive plate corrosion and this can reduce the useful life of the cell by up to 30%.

Removing the float charge for a proportion of service life can reduce this effect, providing the cells do not suffer any measurable discharge in the process. In addition, the small pulses of charge current regularly experienced during life cycling can assist in preventing the formation of plate sulphation, without deleterious effects. This is a safer and more reliable form of the system becoming known in the industry as 'opportunity charging'.

A useful side-effect of life cycling is its ability to reduce the possibility of thermal runaway. This has been known to affect cells which are continuously subject to float charge, particularly when the battery in question is in a confined space or has little air circulation.

■ **Lifetime data log of voltage and temperature:** Manufacturers are continually pressed by standby battery system users for extended warranty periods, often of five years or more. In order to safeguard themselves, the manufacturers normally insist on periodic battery checks of voltage and temperature during the warranty period, sometimes with an annual discharge test. Since they are periodic and not within the control of the manufacturer, these checks are not always satisfactory and are usually costly to the user. A cell-mounted module can provide a lifetime data log of terminal voltage and temperature to address this issue.

■ **Exhaustive Discharge Protection (EDP):** It is normal in charger/UPS systems, and even battery monitors, to preserve the battery by terminating a discharge based on the average cell voltage. This average is obtained by dividing the overall voltage by the number of cells in the battery. The difficulty with this method is that weaker cells can be of a much lower terminal voltage than the battery average, and may be exhaustively discharged well before the battery as a whole has reached its termination voltage. This can damage these cells permanently, leading to premature failure in the long term. A highly accurate, dynamic 'Time To Run' (TTR) generic algorithm has been developed, which will give warning if any individual cell is approaching exhaustion. Decisions may then be taken, possibly pre-programmed into the overview system, as to whether to shut down the UPS or reduce the less important parts of the critical load.

At the end of a discharge and recharge cycle, something that may only happen once a year or so in stationary batteries, the battery returns to a small maintenance charge, often called a 'float' charge. This charge is normally only about 1mA per ampere-hour of battery and, so, is perhaps only a few hundreds of milliamps. If the cells experience a failure mode, this low current can change by several times its original level and, at the same time, the internal temperature of the cell can rise or fall significantly.

It has historically been extremely difficult to accurately monitor and trend current at float levels of a few tens to a few hundreds of milliamps, since a discharge of several hundred amps will have to pass through the same transducer. This will cause remanence (hysteresis) in the transducer and, on its return, to float levels the zero current point may have 'jumped' several amps, never to return to its original point. This, of course, makes trending impossible.

Make It Comprehensive

LEM believes that, to be meaningful, the monitoring of standby battery parameters must be as comprehensive as possible. To that end, in addition to voltage, impedance and discharge performance per cell, LEM already monitors internal cell temperature as standard. It is also developing a fluxgate technology float-charge transducer capable of better than 10mA resolution, with little or no temperature drift and virtually no remanence after a high current discharge.

Taken as a whole, these advances can change the role of the battery monitor from an expansive addition, the cost of which is perceived to be of value only to the most sensitive installations, to that of an extremely cost-effective, integral, life management system, essential to the service life of every VRLA battery.

The Sound of Silence: Transformer or Solid-State?

Despite the fast growing digitisation of the electronics world, the vinyl and analogue aficionado is still alive. Moreover, it's a world-wide growing market with increasing demand for excellent phono amplifiers for moving coil (MC) cartridges. Unfortunately, many so-called high end (and high price) products show lousy signal-to-noise (SN) figures, far away from what is theoretically achievable.

But there are solutions for lowest-noise RIAA pre-amplifiers for use with a specific MC cartridge. There are two alternatives to connect an MC cartridge to an output voltage lower than 1mVrms to an amplifier chain. The two-stage solution consists of a step-up transformer or a solid-state/valve pre-pre-amp (stage 1) attached to a moving magnet (MM) RIAA amp (or phono amp = stage 2) with an input sensitivity of approximately 5mVrms. As such, it creates enough output voltage to drive a pre-amp.

The other option is the full solid-state or valve solution in one stage, including the two different stages. Although the valve driven pre-pre-amp or one-stage solution might be possible to design, inherent obstacles make it impossible to meet the high SN ratios that can be achieved with other approaches.

For low output voltage producing MC cartridges it's extremely hard to find the right lowest-noise input section. An additional noise-driving factor is the cartridge's source resistance, while its inductance doesn't play an influential role. As a typical representative of pre-amp challenging MC cartridges, I've chosen a cartridge with output voltage of only 0.35mVrms at 1kHz and 5cm/s velocity, with source resistance = 43R0 and coil inductance = 56µH, the Denon DL-103 (no 2798). It's not too expensive and it sounds excellent.

Benchmarks

Before I started developing a suitable amplifier, I tried to get a benchmark on SN ratios of excellent MC pre-amps. I've checked several test magazines about test reports on MC pre-pre-amps (two-stage approach) and MC pre-amps (one-stage approach). This survey ended up in very mixed messages: it is nearly impossible to compare SN measurement results from one magazine with those of another. In one case they've measured with the input shorted, in another with an input load of 20R, in yet other with 25R, and so forth.

The next obstacle is measurements with A-weighting filters: with or without IEC roll-off at 20Hz. Standard A-weighting filters are allowed to have enormous tolerances. They are developed for sound measurement purposes only and not for amp noise measurements. So, if you have two results from different measurement setups you can't compare them exactly. Viewed from an SN standpoint alone – but for me the most important one, the best pre-amp I could find was the Linn Linto. A-weighted measurement results for $SN_{ariaaLinto25}$ were claimed to be -81.0dBA/0.5mVrms with 25R input load in a frequency band of 20Hz–20kHz ("stereoplay" 04-1998, measured with an Audio Precision measurement instrument).

With reference to an input voltage of 0.5mVrms and a frequency band B = 20Hz–20kHz RIAA-equalised and A-weighted $SN_{ariaa25}$ for a 25R resistor is -82.735dBA. Thus the SN-delta $DN_{ariaaLinto25}$ for the RIAA equalised and A-weighted Linn MC-RIAA pre-amp is 1.735dB ($SN_{ariaaLinto25}$ minus $SN_{ariaa25}$) [Note: DN should not be mistaken for the noise figure NF of an amplifier. NF relates to the noise factor F, which as a power ratio includes both noise voltages and noise currents. But in the case of an unclear noise current situation DN sufficiently shows differences in SN performance of amplifiers].

The noise voltage e_{NR} of a resistor R is $\sqrt{(4kTRB)}$. With reference to an rms voltage U and a frequency band $B = (f_{high} - f_{low})$, the non-equalised and non-weighted SN_{ne}(dB) of R is:

$$SN_{neR} = 20\log\{\frac{1}{U}\sqrt{\frac{1}{B}[\int_{f_{low}}^{f_{high}} e_{NR}^2\, X(f)^2\, df]}\} \quad X(f)^2 = 1\ ! \quad (1)$$

Including the factors $X(f)^2 = R(f)^2$ or $X(f)^2 = \{R(f)^2 \times A(f)^2\}$ into **Equation 1** can calculate any RIAA-equalised (SN_{riaaR} , SN_{sriaaR}) and A-weighted (SN_{ariaaR}) SN ratios of R as well [R(f) = RIAA transfer and A(f) = transfer of A-weighting filter, k is Boltzmann's constant, T is the absolute room temperature (300°K = 27°C); see also EW 05-2005, p28, "Adventure: Noise"].

If the Linn Linto is really the record holder the pre-amp I tried to develop, it should beat these figures or, at least, it should hit the same bottom line. But how can I find out the right approach to meet this goal for an input load of 43R?

MC Pre-Amp Problems

In the past, quite seldomly, electronic magazines specifically picked up the MC pre-amp noise problem. In the middle of the eighties of last century Douglas

In this article, Burkhard Vogel analyses different approaches to solutions for lowest-noise RIAA pre-amplifiers for use with a specific MC-cartridge

Self did a remarkable job on this issue (E&WW 12-1987, "Design of moving-coil head amplifiers"). That's why his design of a MC pre-pre-amp became mathematically compared with the (more modern?) design of the Linn. To convert the measurement figures of the two amps into those with an input load of 43R, you have to "calculate back" the A-weighted, RIAA-equalised SN figure of the Linn for a 25R input load (-81.0dBA) by subtracting the RIAA and A factor = -7.935dB. To calculate this, it goes as the following:

If $SN_{ariaaAMP}$ (dBA) of a specific amplifier AMP is given, you can calculate certain SNs (dB) with the following equations and SN factors (dB). The equations are valid for white noise and purely resistive input loads only. You always have to calculate back to SN_{neAMP}(dB) first (see **Equation 2**), followed by an addition of the chosen equalisation or weighting factor.

$$SN_{ariaaAMP} - SN_{ar} = SN_{neAMP} \quad (2)$$
$$SN_{aAMP} = SN_{neAMP} + SN_a \quad (3)$$
$$SN_{riaaAMP} = SN_{neAMP} + SN_r \quad (4)$$
$$SN_{sriaaAMP} = SN_{neAMP} + SN_{sr} \quad (5)$$

SN figures of the transfer functions R(f), R(f)+A(f), A(f) and S(f) (S-filter) become:

$$\text{20Hz–20kHz:} \quad SN_r = -3.646\text{dB}$$
$$SN_{ar} = -7.935\text{dB} \quad SN_a = -2.046\text{dB} \quad (6)$$

$$\text{355Hz–20kHz:} \quad SN_{sr} = -7.853\text{dB} \quad (7)$$

The following calculations will lead to wrong results:

$$SN_{riaaAMP} \neq SN_{ariaaAMP} - SN_a \quad (8)$$
$$SN_{aAMP} \neq SN_{ariaaAMP} - SN_r \quad (9)$$

Consequently, the non-weighted and non-equalised $SN_{neLinto25}$ = -73.065dB. That is the basis for the calculation of the input referred noise voltage $e_{NLinto25}$, including the noise voltage of the source resistance of 25R and the noise voltage of the pre-amp. Subtraction of the noise voltage of the 25R resistor leads to e_{NLinto}, the input referred noise voltage of the Linto pre-amp. Referenced to √1Hz and with an assumption for the input referred noise current i_{NLinto}, you can calculate the input referred noise voltage $e_{NLinto43}$ of the Linto with an input load of 43R.

The results of this process are: $SN_{ariaaLinto43}$ = -79.253dBA; $SN_{ariaa43}$ = -80.380dBA; thus, $DN_{ariaaLinto43}$ = 1.127dB. The input noise current doesn't play a vital role in the calculations. A typical value for a solid-state multi-input transistor solution with DC current gain >400 is approximately 3pA/√Hz. A change from 2 to 6pA/√Hz worsens the SN figures by only 0.1dB.

It's much more difficult to calculate Self's design. I assume SN was measured with input shorted (SN = -139.5dBu, 400Hz–22kHz). Otherwise, the SN figure would have been very much lower. This result of the non-equalised pre-pre-amp is measured with an hp-filter which cuts away most of the lower frequencies (f_c = 400Hz). It is best to overcome the measurement difficulties that, in most cases, will occur when measuring solid-state devices being driven by high collector currents – typically for low source resistance designs. Unfortunately, Self's filter is not standard at all – but it should be. I call this SN measurement method S (Self)-weighting and I will use it throughout the whole exercise in comparing its results with the A-weighting case. As a standard application this kind of method would make things a lot easier, especially comparisons. My own S-filter is a fifth order +0/-0.1dB Chebyshev hp-filter with a cut-off frequency of 355Hz (**Figure 1**).

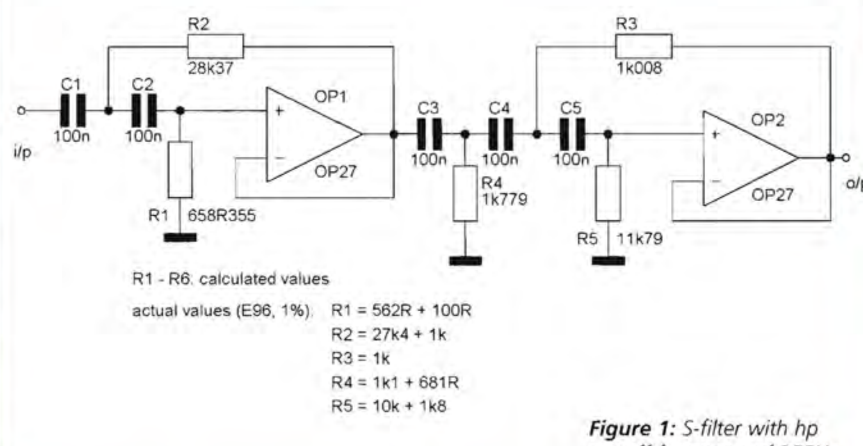


Figure 1: *S-filter with hp cut-off frequency of 355Hz*

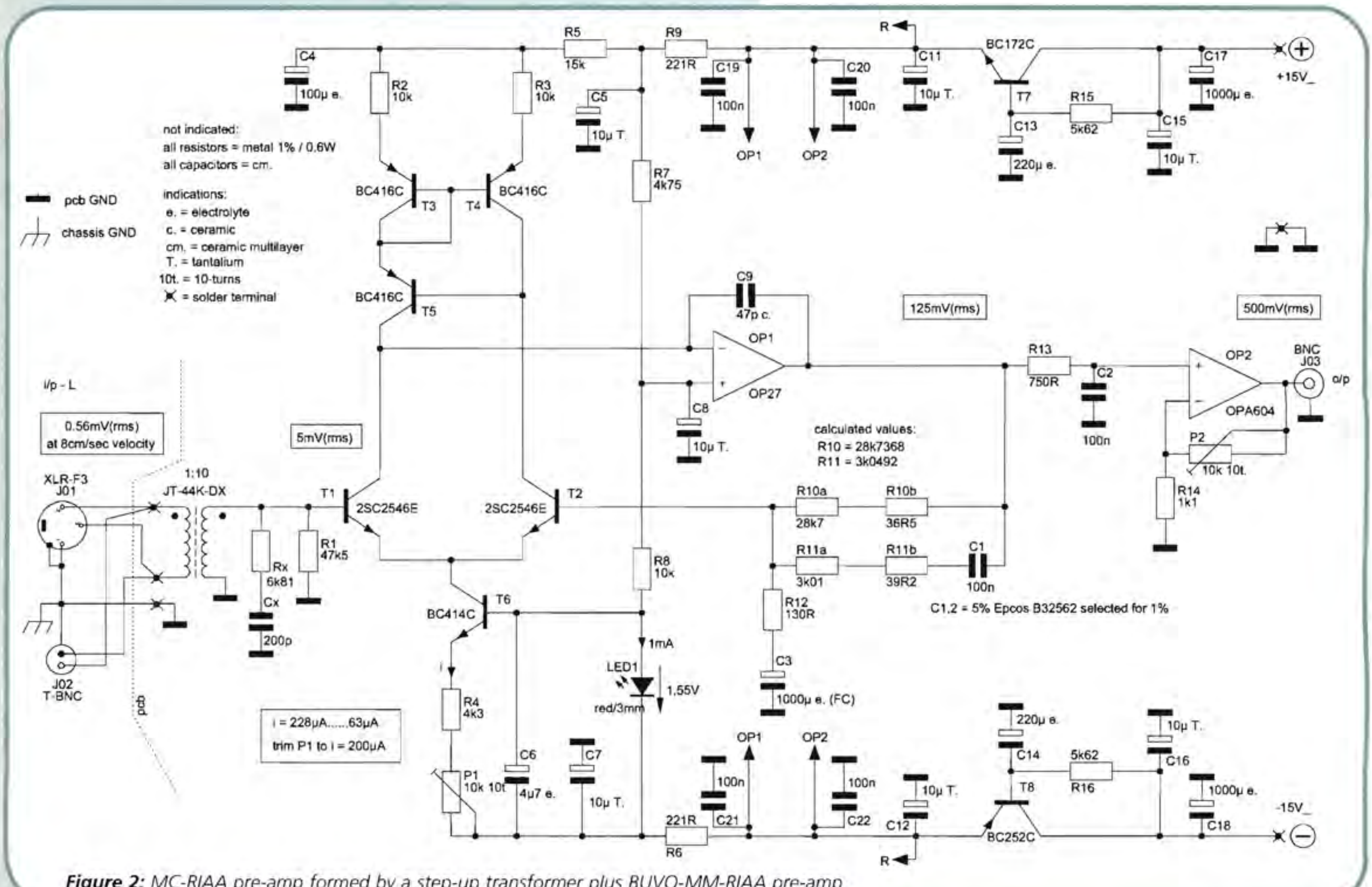


Figure 2: *MC-RIAA pre-amp formed by a step-up transformer plus BUVO-MM-RIAA pre-amp*

The figures of the conversion of Self's (DOSE) data into the ones I wanted to get for comparison look as follows [referenced to an input voltage of 0.5mVrms/ 1kHz, input load = 43R, input resistor = 510R (the reason for which will be explained a bit later), frequency band 20Hz–20kHz, MM-RIAA pre-amp with 5534 op-amp): $SN_{riaadose43}$ = -73.840dB, $DN_{riaadose43}$ = 2.214dB; $SN_{ariaadose43}$ = -78.167dBA, $DN_{ariaadose43}$ = 2.214dB; $SN_{sriaadose43}$ = -78.160dB, $DN_{sriaadose43}$ = 2.206dB.

It's funny but real: by accident my S-filter nearly creates the same SN figures like my precision A-weighting filter (EW12-2004). To show the tiny differences I express calculated results with three digits after the decimal point and round them to one digit in tables. In my handicraft box I found five 100nF capacitors with tolerance <1% and the resistors shown in Figure 1. This is the only reason why the S-filter design ended up with f_c=355Hz.

For the Self two-stage design (MC pre-pre-amp plus MM-RIAA pre-amp), the SN data is shown in **Table 1**, columns D and E. The calculations were carried out without Self's additional IEC-filter (described in his "Audio" book). Because of its voltage divider situation at the input, this filter arrangement worsens the figures by additional 0.4dB. Another disadvantage of Self's two-stage approach is the fact that, in conjunction with the input resistance of the second stage, the output resistance of the first stage worsens

type of pre-amp	Douglas Self Design (3 x 2N4403) + BUVO-MM 2SC2546	+ DOSE-MM 5534	+ DOSE-MM 5532	h_{FE} = 400 I_{C3} = 3mA	Linn Linto	Musical Fidelity XLP	Resistor R0 43R
SN + type of equalisation	**calculated**						
SNriaa	-74.3	-73.8	-73.5	-74.8	-74.9	-69.4	-76.1
SNariaa	-78.7	-78.2	-77.8	-79.0	-79.2	-73.7	-80.4
SNsriaa	-78.6	-78.2	-77.8	-79.0	-79.2	-73.6	-80.4
Deltas	**R0 calculated minus amp calculated**						
DNriaa	-1.7	-2.2	-2.5	-1.3	-1.1	-6.7	
DNariaa	-1.7	-2.2	-2.5	-1.3	-1.1	-6.7	
DNsriaa	-1.7	-2.2	-2.5	-1.4	-1.2	-6.8	

Table 1: *Calculated SN in dB of various MC-RIAA amp solutions (input load 43R, reference voltage 0.5mV, frequency band 20Hz-20kHz)*

SN_{ariaa} by 0.880dB/1.198dB (op-amps 5534/5532).

Hence, if I would take the Self design approach as the input section of a one-stage MC-RIAA pre-amp (Table 1, column F), the SN figures of columns D, E could be improved by 0.880dB or 1.198dB.

I also calculated the Self pre-pre-amp connected to my (BUVO) MM-RIAA pre-amp (**Figure 2**), without transformer and Rx, Cx. The resulting SN numbers are shown in column C of Table 1. They look a bit better than those of Self's two-stage design, because my MM-RIAA pre-amp has lower input noise voltage and input noise current than the 5534 or 5532 op-amps ($\sqrt{2}*1.536nV/\sqrt{Hz}$ and $0.2311pA/\sqrt{Hz}$). But these results are not as good as if I was to develop a new MC-RIAA pre-amp with an adapted Self input section. That's what I finally did.

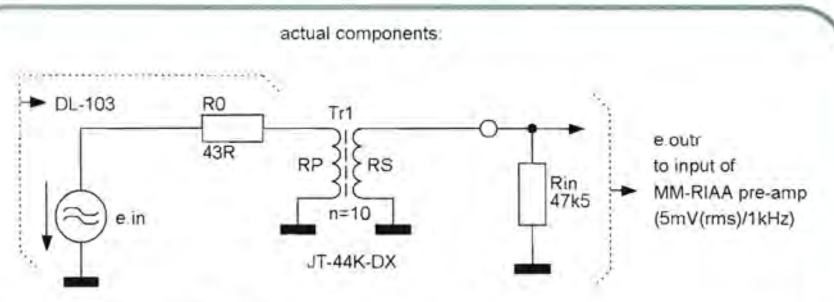


Figure 3a: *Transformer circuit*

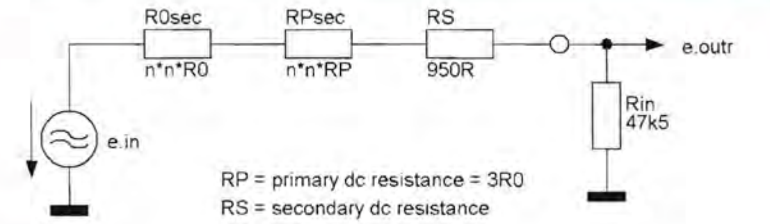


Figure 3b: *Transformer circuit's equivalent*

The Transformer Solution

Without big mechanical work, a step-up transformer could be fixed inside the MM-RIAA pre-amp case. A very good help on the selection of the right step-up transformer is offered on the Jensen Transformers website (www.jensen-transformers.com). With the given equations it is easy to understand how transformers work and perform. I checked the products of several transformer suppliers: Sweden (Lundahl), Germany (Pikatron, experience electronics), UK (Sowter) and the US (Jensen).

Source resistance R0 plus primary coil resistance RP plus secondary coil resistance RS parallel with the input resistance Rin of the MM-RIAA pre-amp form the new total input load of the MM-RIAA pre-amp. The impedance of the Rx and Cx sequence can be ignored in this calculation (Figure 2). It only keeps the frequency response flat at the upper end. Unfortunately, R0 and RP have to be multiplied with the square of the coil turns n^2 ($n = 10$, $n^2 = 100$, see **Figures 3a** and **3b**). Thus, to create lowest noise at the input of the MM-RIAA pre-amp you have to try to find a transformer with RP and RS as low as possible.

Here, I won't discuss other selection parameters like distortion, frequency response, overload etc. The respective figures (on paper) of the transformers I've checked were all good enough. They don't play the same role like the noise making ones. RP = 3R and RS = 950R for the Jensen transformer are by far the best figures, followed by the Pikatron: RP = 9R4 and RS = 380R. The two other types have very much higher values, Sowter only offers a step-up transformer for high source resistances with n = 12.5.

With the 47k5 input resistor of my MM-RIAA pre-amp, the 43R input loaded Jensen transformer produces a total input load of 4k969 (Pikatron: 5k045) [Jensen Transformers Application Note AS040]. The respective SNs are given in **Table 2**,

type of pre-amp	2 LM394 $h_{FE} = 530$, $R_B = 40R$ $I_{C4}{}^* = 12.05mA$		2 MAT02 / SSM2210 $h_{FE} = 680$, $R_B = 30R$ $I_{C4} = 6.7mA$		1 BFW16A $R_B = 4R^{**}$ $I_{C1} = 20mA$	Jensen transform. + BUVO-MM 2 x 2SC2546		Resistor R0 43R
SN + type of equalisation	calc.	meas.	calc.	meas.	calc.	calc.	meas.	calc.
SN_{riaa}	-74.8	-71.7	-75.0	-72.5	-73.9	-74.1	-73.6	-76.1
SN_{ariaa}	-79.1	-78.9	-79.3	-79.2	-78.2	-78.4	-78.4	-80.4
SN_{sriaa}	-79.0	-78.8	-79.3	-79.2	-78.1	-78.3	-78.4	-80.4
Deltas	**amp calculated minus amp measured**							
SN_{riaa}	-3.1		-2.5			-0.5		
SN_{ariaa}	-0.2		-0.1			0.0		
SN_{sriaa}	-0.2		-0.1			0.1		
Deltas	**R0 calculated minus amp calculated**							
DN_{riaa}	-1.3		-1.1		-2.2	-2.0		
DN_{ariaa}	-1.3		-1.0		-2.2	-2.0		
DN_{sriaa}	-1.3		-1.1		-2.3	-2.1		
Deltas	**R0 calculated minus amp measured**							
DN_{riaa}	-4.4		-3.6			-2.5		
DN_{ariaa}	-1.5		-1.2			-2.0		
DN_{sriaa}	-1.6		-1.2			-2.0		

Icn^* = sum of n collector currents; ** $h_{FE} = 40$

Table 2: *Calculation and measurement results in dB (rounded to one digit after the decimal point) for various input devices with reference to an input load of 43R, an input voltage of 0.5mV/1kHz and a frequency band of 20Hz-20kHz*

columns H, I. These figures are not as good as those of the Self pre-pre-amp plus the BUVO-MM-RIAA pre-amp (Table 1, column C). But this transformer/MM-RIAA-pre-amp chain configuration has an advantage over all the full-blown solid-state designs: its low frequency noise [mainly shot – and 1/f- (flicker-) noise] is very much lower than that of the solid-state case (Table 2, columns C-F, line 6). That's why there is a big difference between measured (RTA and FFT with 50 times averaging) and calculated values of SN_{riaa} for the two MC-RIAA pre-amps I've built: 2.5dB and 3.1dB. In the transformer case it's only 0.5dB.

The transformer setup also triggered the choice of the input resistor of the solid state pre-amp: 510R, thus making its input resistance approximately 475R. R_{in} is transformed down by division with n^2. If the connecting cable between transformer output and MM-RIAA pre-amp input is too long (>20cm), then there will be a good chance to catch mains interferences because of the high output impedance of the transformer (>5k) and the higher input resistance of the MM-RIAA pre-amp. That's why I strongly recommend to directly place the transformer into the MM-RIAA pre-amp case.

Another "dangerous" point is the wiring between turntable and transformer input. The best thing to do is to take the symmetrical cable solution. I've installed Twin-BNC plugs and jacks (Emerson/Vitelec, UK) and XLR types as connectors, and the cable is Mogami (no 2549). Deviation from the exact RIAA-transfer is less than ±0.1dB. The whole arrangement sounds excellent.

However, I still wanted to beat the Linto noise figures with a better solid-state solution.

The Solid-State Approach

The solid-state design is shown in **Figure 4**. The measurement and calculation results are given in Table 2, columns C-G. A front-end with four parallel-working transistors (T1-4) feed OP1. It was easier to select two double-transistors than three or four single ones (by accident I've installed two LM394 with a heavy h_{FE} difference of 250: all SN figures deteriorated by only 2dB).

The LM394 was chosen because its base spreading resistance R_B (= 40R) equals that of Self's transistors (2N4403). The MAT02/SSM2210 is claimed to be the follower of the LM394, with better low frequency noise data. It really does a bit better with its R_B of 30R.

Normally, low-R_B BJTs in lowest-noise designs are superior to those with higher R_B. This only is true for

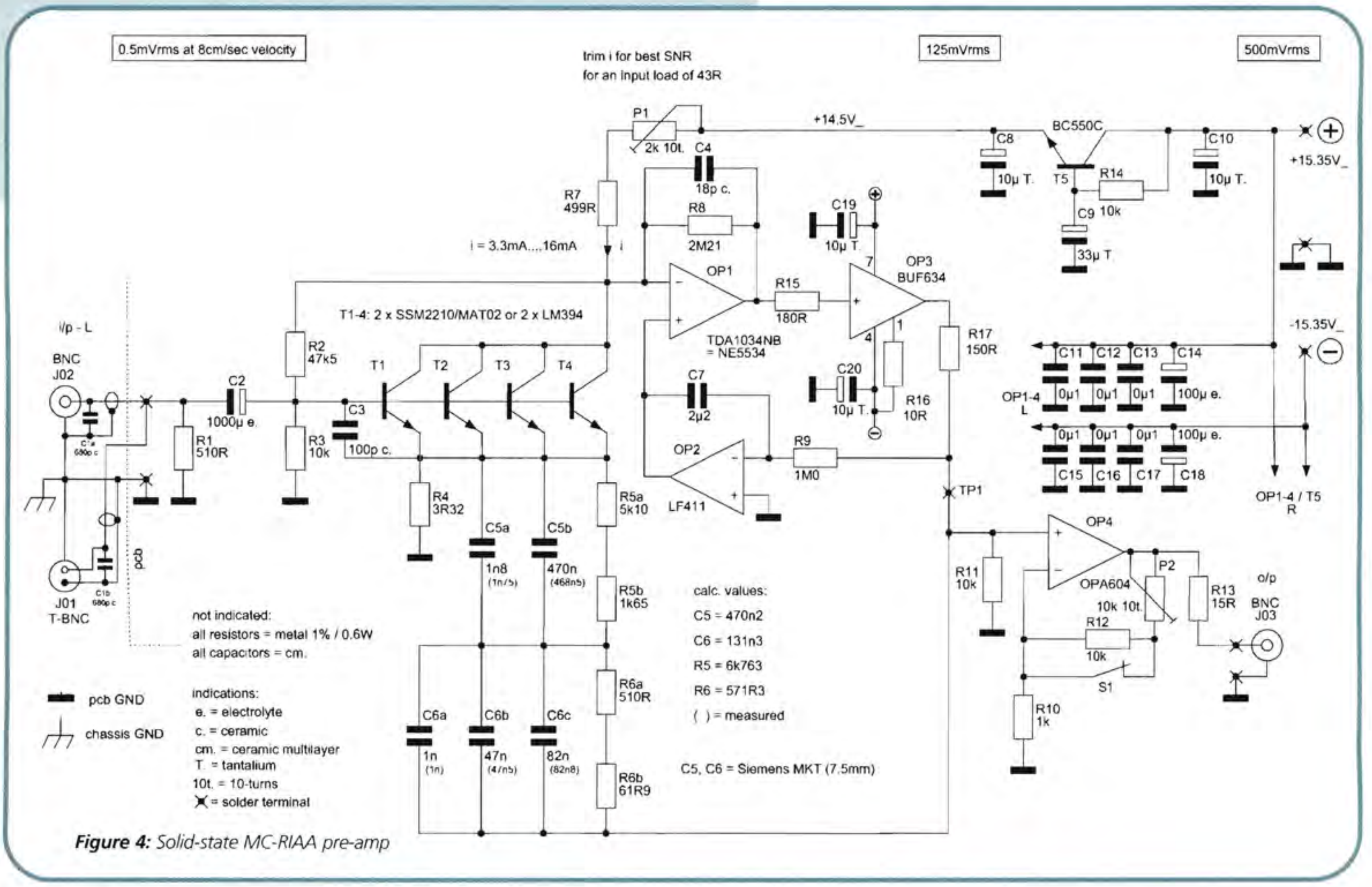


Figure 4: Solid-state MC-RIAA pre-amp

very low source resistances. But for a source resistance of 43R, a device with R_B of only 4R0 and h_{FE} = 40 (BFW16A), is not able to beat the SN ratios of BJTs with higher R_B and much higher h_{FE} (see Table 2, column G). It's hard to find a lowest-R_B transistor with h_{FE} >> 40. The latter is essential for low input noise currents. Basically, the (base) input noise current i_N of any BJT can be calculated as follows:

$$i_N(I_C) = \sqrt{\frac{2qI_C}{h_{FE}}} \qquad (10)$$

(q = elementary charge, I_C = collector current)

For comparison, in column H of Table 1 you'll find the calculated figures of a typical representative of many MC-RIAA pre-amps with SN_{ariaa} between -72.0dBA and -78.0dBA with 43R as the input load (Musical Fidelity XLP: with 25R input load SN_{ariaa} = -74.1dBA/0.5mV/20Hz–20kHz). Its 2SC550 input transistors are high frequency power devices from Toshiba. I guess they have very low R_B. But in this case, it doesn't help a lot to reduce the noise level extremely.

OP3 (BUF634) serves as current booster to enable the connection of a very low-impedance RIAA feedback network (77R at 20kHz) between OP3's output and the emitters of T1–4 and R4. To avoid ringing, some precautions have to be implemented around OP3: R17 at the output of the buffer, R15 at its input. The bandwidth is set to nearly maximum by R16. C18 and 19 have to be placed as near as possible to OP3. To minimise the noise voltage level of the amp, the optimal collector current can be trimmed with P1. This is checked by inserting an S-filter (Figure 1) between the output of the pre-amp and an appropriate measuring tool.

The high value of the input capacitor C2 is essential to keep its low-frequency impedance as low as possible. If you have problems with electrolyte capacitors inside the amplification chain, I strongly recommend to read the respective debate in E&WW in 1988, after Self published his pre-pre-amp article in 12-1987. I only did hear tiny differences between very expensive, cheaper and bridged capacitors that I tested with the circuit of **Figure 5**. Finally, I chose one from Panasonic (FC). To exactly hit the RIAA transfer, the value of C7 (2µ2) should not be changed. With that, the deviation of the pre-amp's RIAA transfer is of a maximum ±0.1dB.

Concentration on noise reduction in amplifiers makes no sense, as long as the power supply is not noise-optimised as well. Attached to a separate Al-case, a Talema toroidal transformer is followed by a rectifier, high value capacitors and two gyrators. They generate the main positive and negative supply voltages that are stabilised by LM317/337 devices (±20V). A shielded 1.5m cable connects power supply and pre-amps. To get extreme low noise on the voltage lines inside the pre-amp case, a further supply voltage noise reduction treatment takes place with a µA723 in lowest noise mode, followed by a 2N3055. This arrangement produces ±400mA maximum current for the final output voltages of ±15.35V DC. Negative voltage is drawn off from the final positive output voltage line via an inverter (OP27) and a PNP-Darlington transistor configuration with 2N2905A and 2N3055.

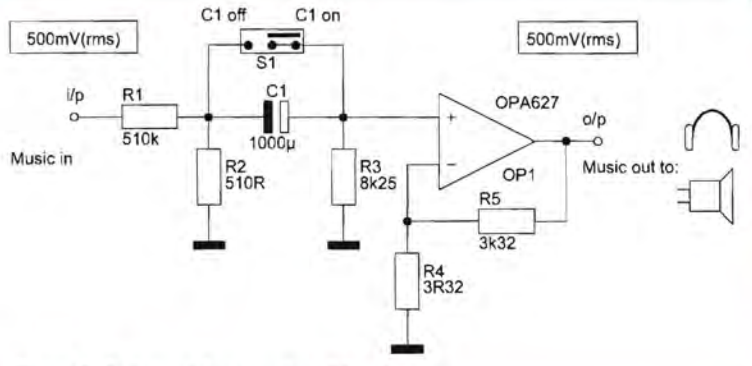


Figure 5: *Test circuit for capacitors C1 = d.u.t.*

Sounding Good

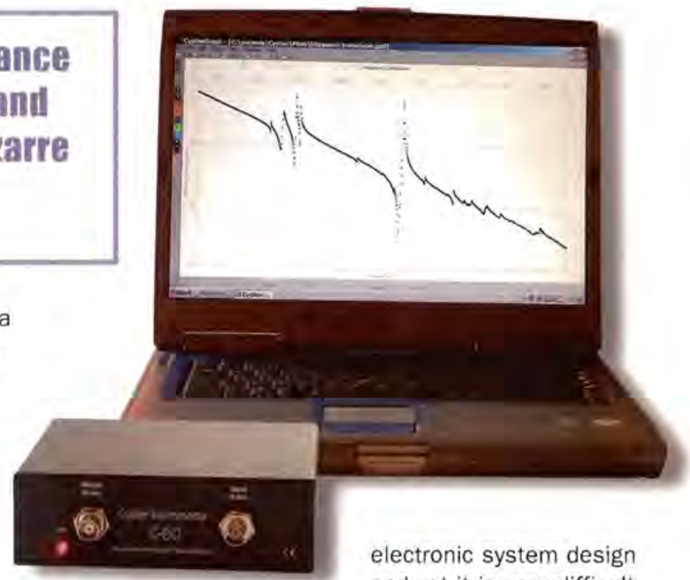
Both types of MC-RIAA pre-amps sound very good. The SN difference between the transformer and solid-state solution is apparent (especially at the lower end of the frequency band), but marginal. With the loudness pot set in a 2pm position, noise can't be heard at a listening distance of 30cm from the loudspeakers. It really is silent.

Finally, it will be a question of expenses and listening tests to decide the alternative. With a DL-103 as input device, any further attempts to reduce noise make no sense because of the fast growing physical limitations. To get capacitor-free direct coupling, a long-tailed pair of input transistors of the solid-state solution (e.g. four MAT02/SSM2210) would downgrade all SN ratios by approximately 1dB. Further SN improvements can only be achieved with MC cartridges with lower source resistance and/or higher output voltage [e.g. Ortofon "Rondo" – its price is five times higher than that of the DL-103], and 6R0 and 0.9mVrms/1kHz/8cm/sec. So, with reference to a nominal amplifier input voltage of 0.9mVrms/1kHz improving all SN ratios of Table 2, columns E and F, by 9.3dB. For transformer coupling you need another transformer being able to work with 6R0 input load.

Measured with a precision anti-RIAA circuit, very low phase angles could be observed: +3.5° (solid state) and +5.4° (transformer) at 20Hz, -0.5° (solid state) and -14.4° (transformer) at 20kHz. In addition, the bottom line set by the Linto could be hit mathematically with a 43R input load (Linn: -79.253dBA vs. MAT02: -79.340dBA) and measurement-wise with a 25R input load (Linn: -81dBA vs. MAT02: -80.6dBA, but still with I_{C4} = 6.7mA, the optimal collector current for 43R input load – see Table 2).

Simple Impedance **Measurements**

Tim Orr and Adam Fullerton carry out impedance measurements on a variety of components and networks. The results illustrate the often bizarre behaviour of electronic devices



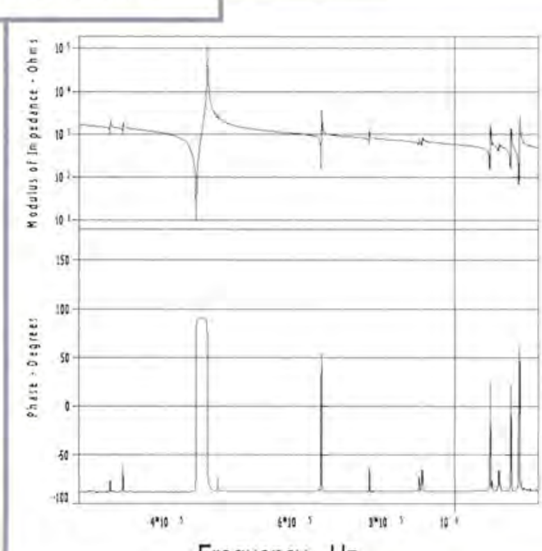
All objects exhibit electrical impedance. It is a measurement of the ability of the object to impede or oppose the flow of current when excited by a sinusoidal voltage.

Electrical devices have impedances that are composed of capacitive, inductive and resistive elements, which result in the impedance being 'complex' and frequency dependant. Complex impedance exhibits a non-zero phase-shift between the current passing through it and the voltage across it.

Affecting Operation

Impedance determines the proper operation of electronic equipment and systems. Data and video cables should have the correct characteristic impedance or reflections will occur, which will destroy the signal integrity. Generally, amplifiers should have high input impedance and low output impedance. Scope probes should present high impedance, so that they do not load the circuit that they are testing. Batteries and power supplies should have very low output impedance, so that they can deliver large output currents without collapsing the voltage.

Figure 1: *Response of a 455KHz resonator*



Impedance is a very important aspect of electronic system design and yet it is very difficult to measure and display. Until recently, testing has only been possible by using large expensive network analysers. The following tests were performed with possibly the smallest machine available – the C60 (see above).

The C60 investigates the opaque world of analogue networks. Electronic, electrical, electro acoustic and other networks are tested with swept sine waves. The unit operates in two test modes. It can measure the reactive response of a two terminal network producing an impedance/admittance and phase graph. Also, it can measure the frequency response of a two port system producing a gain/loss and phase graph.

The test results are graphically displayed on a PC. The impedance testing is very simple; the device being analysed is connected to the output BNC.

The following examples illustrate the often bizarre behaviour of electronic devices. All of the graphs are generated from measurements using the C60; none of them are simulated.

Impedance Measurements – This Is Physics!

Piezoelectric ceramics exhibit strong electro-mechanical properties. Lead zirconium titanate (PZT) is a crystalline material that is commonly used to construct these ceramic devices. It can be shaped into thin discs and rectangular slabs. A sinusoidal driving voltage applied to a PZT crystal will cause it to compress and expand. This produces a mechanical wave that moves through the material at the velocity of sound of that material. The disc or slab geometry

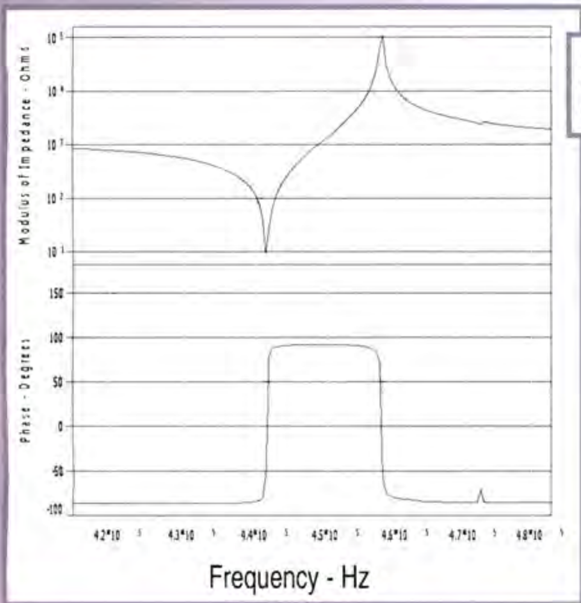


Figure 2: *Complex response of a 455KHz resonator*

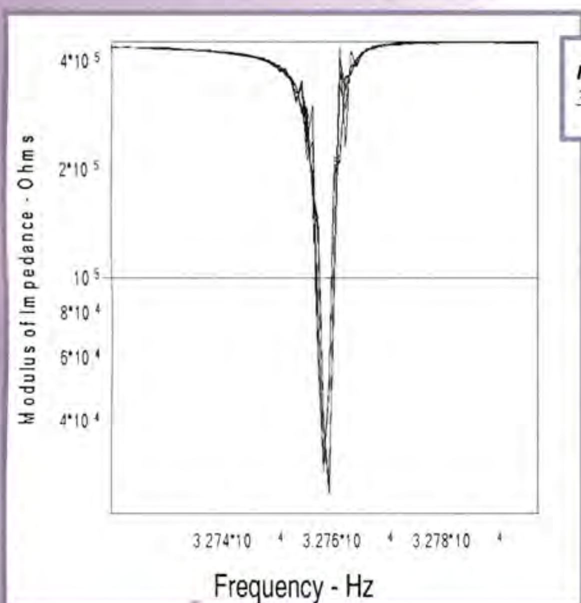


Figure 3: *Response of a 32768Hz crystal*

will produce strong resonance modes which can be exploited to construct electronic resonators.

A fundamental resonance mode for a thin disc is called the radial or 'breathing' mode, where the crystal expands and contracts from the centre node. Another mode is called the thickness expansion mode, which occurs at a half wavelength resonance through the thickness of the crystal.

Also for rectangular structures, there are even more resonant modes. Ceramic resonators exhibit moderate Q factors (500 to 2000) and frequency tolerance (0.5% to 2.0%), but they are smaller and less inexpensive than quartz crystals.

Ceramic resonators are used in electronic circuits to construct low-cost reference oscillators. They are placed in the feedback loop of a high gain amplifier so that they cause oscillation at the fundamental frequency of the resonator. If you think that a ceramic resonator only has one resonance mode, then look at the impedance response graph! The resonator is marked as being 455kHz (**Figure 1**).

The fundamental resonance occurs at 441.3kHz/10Ω impedance and an anti-resonance at 457.9kHz/110kΩ impedance. By zooming into the plot, the phase is revealed in greater detail (**Figure 2**).

The phase plot is the phase difference between the sinusoidal current flowing into the test device relative to the sinusoidal voltage across it. This is the complex impedance response. The response shows classic phase loops that occur at these resonances. At the fundamental resonance, the phase performs an almost 'square' transition. When the phase shift is -90°, the test device behaves like a capacitor. When the phase shift is +90°, it seems to have the behavioural nature of an inductor (except that it cannot store magnetic energy). For every resonant event, there is an attempted phase loop.

Quartz Crystals

Watch crystals are designed to resonate at 32,768Hz (3^{32} Hz). The crystal is used to construct a reference oscillator, which when reduced by a 32-bit binary divider, produces a 1s clock. These crystals are physically very small due to their 'tuning fork' resonance. This cut does little for their frequency stability. An impedance plot (**Figure 3**) shows an impedance dip at resonance. Ten plots with a 1Hz sample resolution have been overlaid to construct this graph. At the 10^5Ω horizontal grid line, the impedance width is 3Hz.

Ultrasonic Transducers

PZT discs can be used as acoustic transducers. Apply a voltage to them and they will transmit sound; apply sound to them and they will generate a voltage. Ultrasonic air transducers are used as echo sounders and rangers in non-contact distance measurement systems. A 40kHz ceramic disc transducer produced the impedance plot as shown in **Figure 4**.

The first resonant peak is at 40kHz but there are many more, including a large one at 280kHz. These devices are very resonant and are very similar in construction to the ceramic resonators discussed earlier. However, they are in direct contact with the air, which dampens the resonances. Normally, a good acoustic transducer will have a relatively flat frequency response. Ultrasonic rangers often work at one frequency. One transducer is used to both transmit and receive and, so, there is no need for a flat frequency response, particularly if the system is run at resonance.

Acoustic Transducer – Loudspeaker and Microphone

Four impedance responses of a studio monitor (a loudspeaker) were also plotted. This unit consists of two loudspeakers, a passive crossover unit and a passive treble control, which causes the impedance

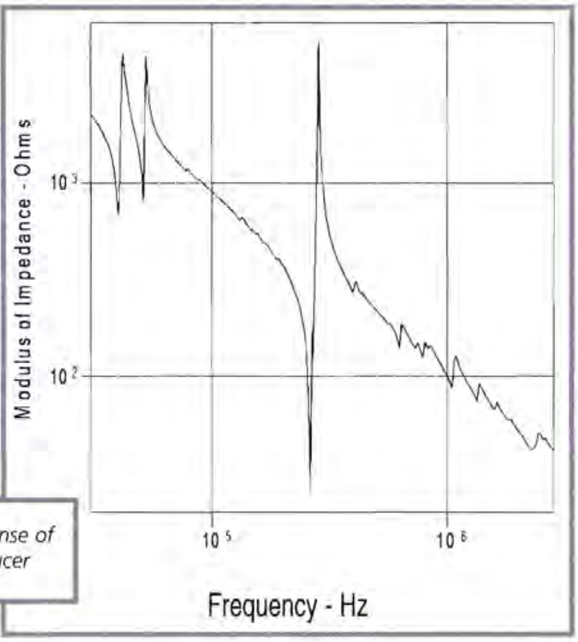


Figure 4: *Response of a 40KHz transducer*

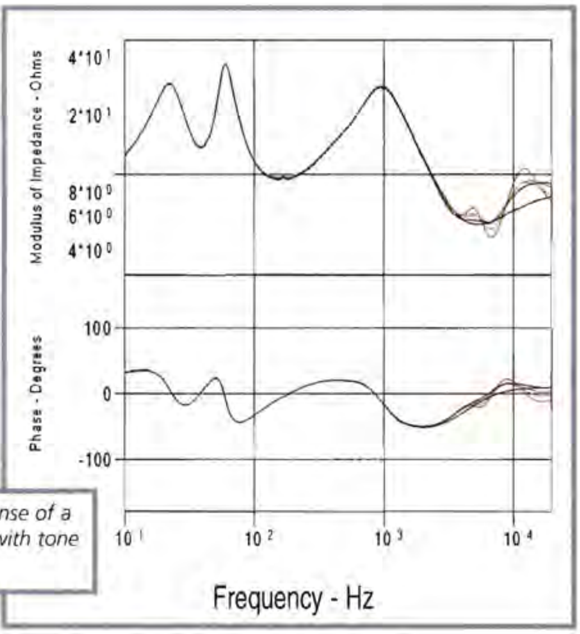


Figure 5: *Response of a studio monitor with tone control*

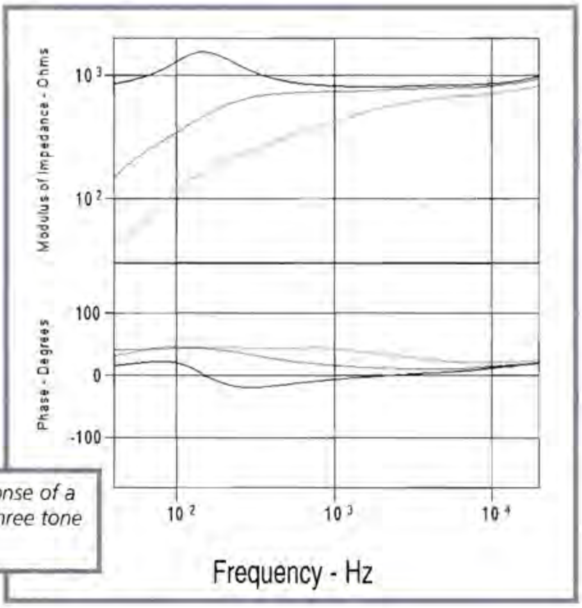


Figure 6: *Response of a microphone – three tone settings*

variation above 4kHz. The phase response in **Figure 5** shows a ±45° variation, which presents a power amplifier with a reactive load that, at times, is half inductive or capacitive.

Loudspeakers are cyclic electromagnetic motors. Self-resonance, back EMF affected by acoustic resistance and passive LC crossover units, makes for an exotic impedance response.

In addition, we measured the impedance response of a moving coil microphone (**Figure 6**). The microphone has three tone controls that are used to adjust the bass (near field) response. These also affect the impedance.

Plots were taken in an acoustically noisy room, which can introduce small measurement errors. The microphone coil is suspended in a magnetic field. The coil is mobile and it is connected to a resonant mechanical system. As a result of this, the impedance is not that of a simple inductor. These plots are not very dramatic; however, an impedance test is a good method for looking for defects in the manufacturing process.

However, reactance does not generate thermal noise. Electrical microphone noise is only generated by the resistive part of the impedance; the reactive part of the impedance is not a noise generator.

Microphone noise = $0.13 \times \sqrt{R}\ nV/\sqrt{Hz}$, where R is the coil resistance.

So, a 400R microphone has a noise voltage of 0.13 x 20 = 2.6nV per root Hertz. The square root of a 20kHz bandwidth is 141. Therefore, the noise in that bandwidth is:

2.6 x 141 = 366.6nVrms or 0.367μVrms

Cable Impedance Measurement

Put two or more insulated conductors together in a long cable and characteristic impedance is formed between them. This is because they virtually occupy the same physical space and so have mutual capacitance and inductance. This impedance is defined by $Zc = \sqrt{L/C}$, where Zc is the characteristic impedance of the cable and L & C are the lumped inductance and capacitance per unit length of the cable.

As we don't have values for either of these, the formula is only useful to cable designers who have control over the physics of the design.

There are two methods of finding out the characteristic impedance of a cable. One, where it is written on the cable drum and sometimes on the cable, and two, if that is too easy for you then you can measure it.

The cable impedance at high frequencies is defined as:

$$|Zc| = \sqrt{|Zopen| \times |Zshort|}$$

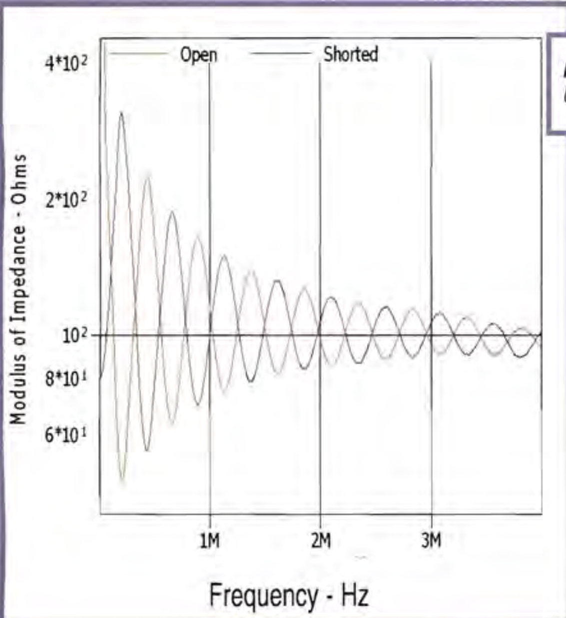


Figure 7: *Response of a USB cable impedance*

An impedance test was performed on a 200m drum of USB cable. The cable is tested with the far end open circuit and then short circuit, producing the graph in **Figure 7**. Note that a linear frequency axis was used. The characteristic impedance can be calculated at any test frequency from the formula above or by viewing the graph. Where the open and shorted curves cross each other, that point is the characte-ristic impedance of that cable length. If the cable length is long enough, the two impedances will converge.

In the graph, the red plot is the open circuit or electric field response. The blue plot is the short circuit or current/magnetic field response.

Battery Impedance

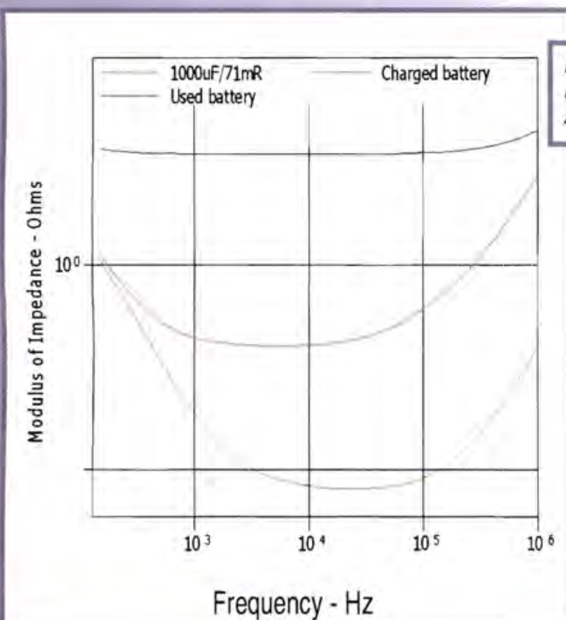


Figure 8: *Battery impedance; two Ni-MH AA cells*

There are many types of batteries. Some have relatively flat output voltage discharge curves, others have large variations. Some are rechargeable, others not. Some self-discharge with enthusiasm, others have a good shelf life. They all suffer from similar problems. Their output voltage drops with discharge. Also, their internal impedance increases with discharge and with the number of times they have been recharged and reused.

A pair of Nickel Metal Hydride rechargeable AA cells was tested for impedance (see **Figure 8**). They were connected to the C60 via a 1000μF low Z capacitor. This blocks any DC current from entering the C60 and damaging it. The green plot is the impedance of the capacitor on its own. It claims to have an ESR of 70mR at 100kHz. The plot indicates 90mR, but also includes the screw terminal adaptor, the C60 output inductance and the wire leads of the capacitor. This plot shows the errors caused by the capacitor coupling. The impedance increases at low frequencies because of the capacitor reactance and increases at high frequencies because of the stray inductance of the test fixture and wires to the batteries.

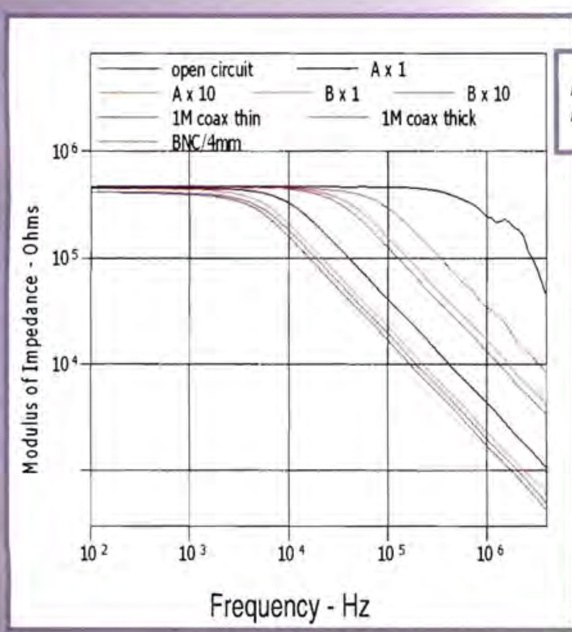


Figure 9: *Scope probe impedance*

The middle plot (red) in Figure 8 is that of a freshly recharged pair of batteries. At 10kHz, the internal impedance is 0.4R. A 1A current surge will cause the voltage to dip by 400mV. The top plot (blue) is that of a pair of the same type of batteries that had powered a digital camera for 50 shots. The internal impedance at 10kHz is 3.5R. A 1A current surge will cause the voltage to dip by 3.5V. Testing the battery impedance is another tool that can be used to monitor battery quality and to predict available battery capacity.

Scope Probes and Test Leads

An X1 scope probe has an input resistance of 1MΩ and an input capacitance of about 100pF. Past 1.59kHz, the probe impedance is dominated by the capacitor. At 1MHz, the 1MΩ scope probe has an

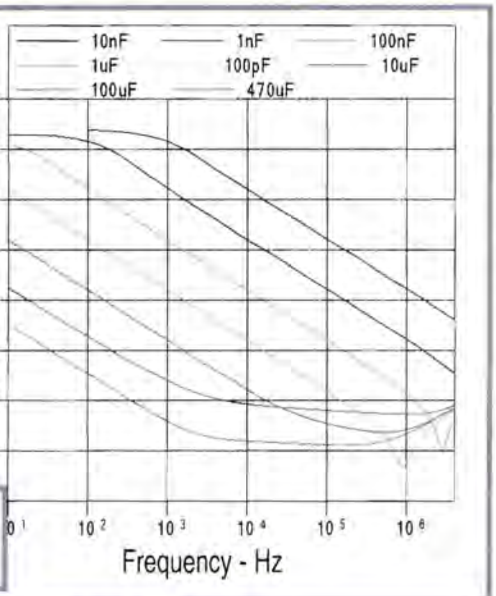


Figure 10: Response of different capacitors

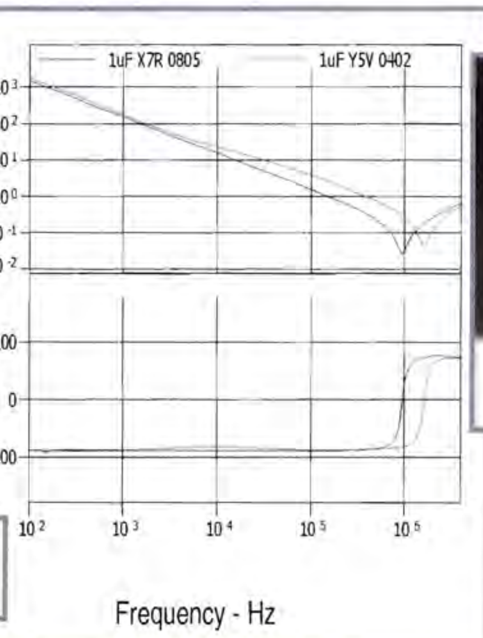


Figure 11a and 11b: Response of dielectric capacitors

impedance of 1591Ω, and at 10MHz it is 159Ω.

Often, a circuit will change its operation when a scope probe is connected because of this impedance loading. A FET scope probe with a 1pF/1MR input capacitance will reduce this problem. The downside is that a FET probe can cost as much as the scope. Another scope probe impedance phenomenon is the earth clip. This forms a nice loop inductor, which can resonate with the probe capacitance. This self-resonance limits the bandwidth of the probe. This effect can be seen by probing a high-speed logic signal and then curling the earth lead around the probe body. The signal seen on the scope has resonant edges that can be changed by modifying the earth clip geometry. The inductance can be minimised by using a probe with a tip and pointed earth ring. For this to work, the part of the circuit being probed needs a local earth pad. This is almost impossible to pre-arrange.

A selection of scope probes and other connectors was tested (see **Figure 9**). The scope probes are referred to as A and B with X1 and X10 settings. These represent loading resistances of 1MR and 10MR. The graph shows how much loading a scope probe will present to a circuit, even at relatively low frequencies. Two coaxial BNC to BNC leads were also tested (blue and mauve). They presented the biggest loading.

The BNC to 4mm adaptor (grey plot) was a surprise. It has an impedance of 34K at 1MHz, which is equivalent to a 4.5pF capacitor. Even this small capacitance shows up on the graph.

Capacitors

Tests were performed on capacitors with radial leads. These leads add parasitic inductance and resistance to the part being tested. Eight different capacitors were examined. The highest impedance plot is a 100pF ceramic capacitor. The subsequent plots are for 1nF, 10nF, 100nF and 1μF, plastic film capacitors. Next was a 10μF, tantalum bead capacitor, followed by a 100μF electrolytic can device; and last was a low impedance electrolytic, 470μF capacitor.

The 1μF and 100nF capacitors show resonances at 1MHz and 2.7MHz, caused by the parasitic inductance in the test setup. The 10μF tantalum capacitor has a characteristic semi-flat response. For some of the response, its impedance curve is better than the 100μF electrolytic capacitor. The low impedance 470μF capacitor, as its name suggests, has the lowest impedance response, making it ideal for the bulk of a power supply reservoir. At high frequencies, the stray inductance causes a rising impedance plot (**Figure 10**).

For the X7R and Y5V ceramic surface mount capacitors, the measurements are shown in **Figure 11a**.

The X7R dielectric has good tolerance (5 to 10%) and is generally well behaved. The Y5V has a poor tolerance (+80% -22%) and a poor temperature coefficient; it is inexpensive and the 1μF capacitor fits into a miniature 0402 (1mm x 0.5mm) package. Y5V makes a good power supply decoupling capacitor, where accuracy is not important. When measured, the 1μF Y5V was 0.7μF. The graph in Figure 11a shows the Y5V capacitor deviating from the ideal performance.

Both parts were soldered into a BNC test header. The resonance is caused by parasitic stray inductance in the test connection, in the order of 23nH. Components with wire leads have bigger parasitic inductance than those of surface mount devices. Better dielectric materials are COG and

NPO. These are higher tolerance and stability. They are also more expensive and it is difficult obtaining parts above 10nF in value.

For impedance measurements, the device under test (DUT) is connected to the output BNC, as close as possible. When a DUT is connected with a cable, then the cable impedance is included in the measurement. **Figure 11b** shows a surface mount 0805 capacitor soldered to a BNC adaptor. Even so, there is still approximately 25nH of stray inductance introduced by the BNC connectors.

Inductors

The impedance response of five different makes of inductors was measured. Each inductor had 10μH printed on them. The main difference between them was the series resistance, which, in turn, would affect their maximum working current, their maximum magnetic field strength and, also, their minimum useful operating frequency. The graph in **Figure 12a** shows a large spread in performance. One device only starts to behave as an inductor at 100kHz.

A large inductor with axial leads is connected using a BNC adaptor (**Figure 12b**). For large value inductors, the stray inductance is not significant.

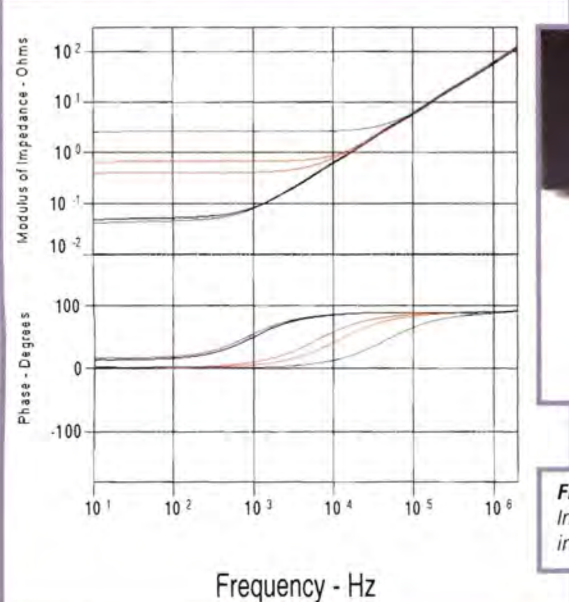


Figure 12a and 12b: *Impedance response of inductors*

Capacitor and Inductor Networks

Capacitors and inductors have a reactance that varies with frequency. They also suffer from parasitic effects that degrade their theoretical performance. Inductance stores magnetic energy and capacitance electric energy. When these two combine, they form resonant circuits. Previous, 'pure' inductors and capacitors turned out to be less than perfect. Their parasitic components produce self-resonance.

Figure 13 shows examples of intentionally tuned circuits constructed from discrete inductors and capacitors. In this example, a 10nF capacitor and 10μH inductor are used to construct resonant circuits. The downward sloping line (blue) is the impedance plot of the 10nF capacitor. The rising slope (pink) is that of the 10μH inductor.

When the two components are wired in parallel (green), the impedance has a peak response at resonance. When the two components are wired in series (brown), the impedance has a minimum value at resonance. The phase plots indicate the transition through resonance. The resonant frequency happens at the intersection of the L and C impedance plots. That is, when $|Z_L| = |Z_C|$, resonance will occur.

A parallel inductor and capacitor combination, with their leads soldered to a BNC adaptor in a series combination and single components are also connected by this method.

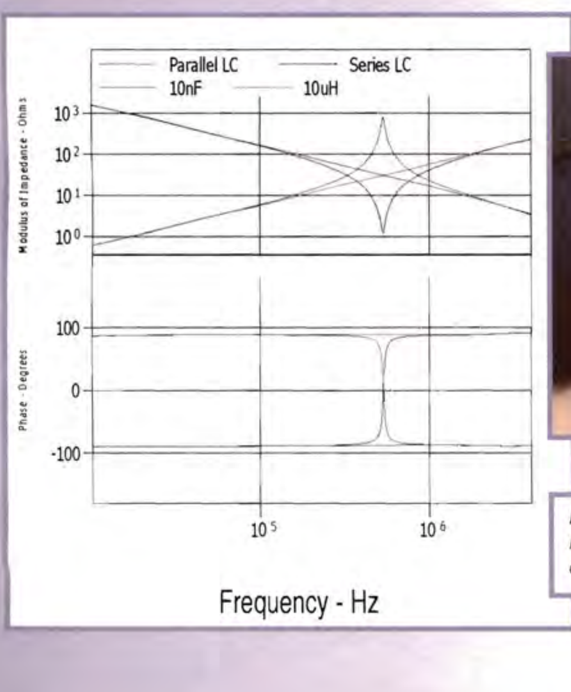


Figure 13a and 13b: *Response of resonant circuits*

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Walking with GIANTS or DINOSAURS?

By Chris Williams, UKDL

Living and working in today's high technology world is both exhilarating and frustrating. Whatever computer, monitor, PDA, MP3 player or flat panel TV users buy today, they just know that there will be a better one available in less than 12 months' time, so should they jump now and buy, or should they wait?

This is a difficult problem that the marketing executives of the large global companies are working hard to address – they really want consumers' money now and not at some unspecified time in the future. More features, more of the 'wow' factor, and above all, a lower price in the shops represent the holy grail of these companies.

> "The factor that will decide if these companies are to become market Giants or Dinosaurs will be the fickleness of the consumer"

But, all of this comes at a price – and a very high price at that. Consider flat panel TVs, for example – the main consumer product driving the massive investments into new production plants in the Far East.

Unlike CRTs that are all made individually, the glass LCD (and plasma) panels are prepared from much larger sheets of glass that are processed in factories. These substrates are referred to by the "generation" of production equipment that was developed to handle and process them. Hence, Generation 6 refers to a substrate glass size of 1.8 x 1.5 metres (x 0.6mm thick for LCDs, 3mm thick for plasma), Gen 7 is 2.0 x 1.8 metres, but Gen 10, for example, will be a massive 2.85 x 3.05 metres. In terms of investment cost, a Gen 7 factory costs around $1bn, whilst a Gen 10 investment will crank up to a staggering $4.25bn.

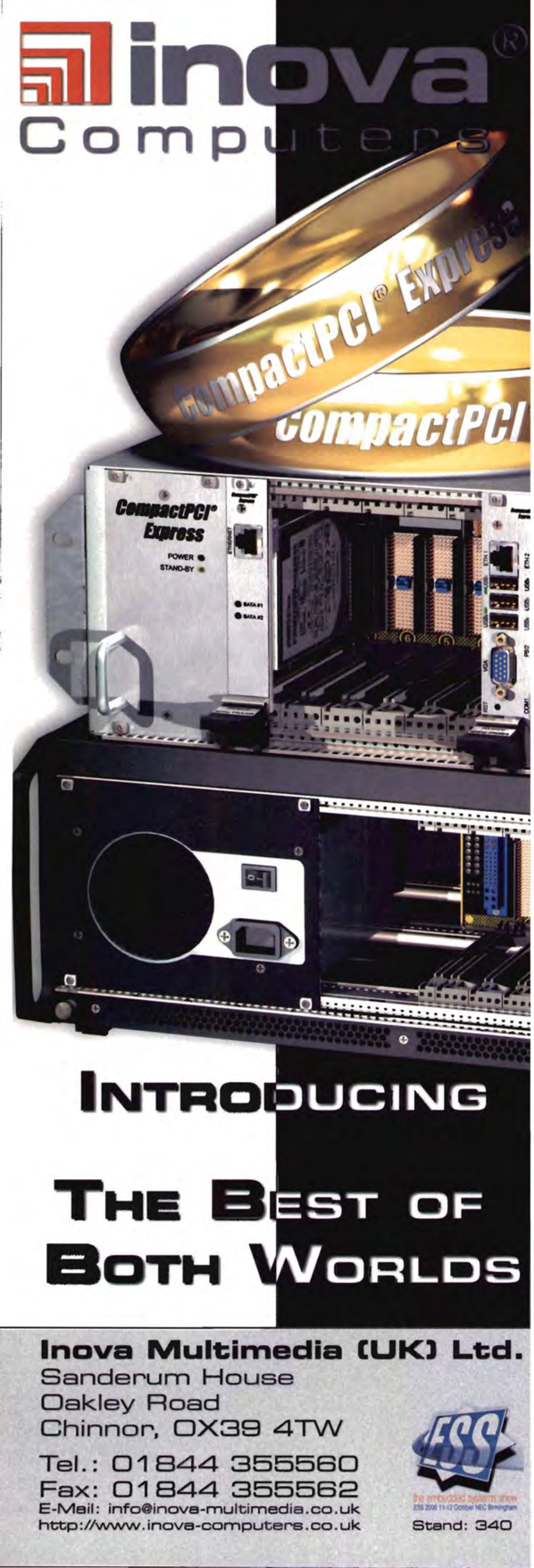
The motivation for the very large companies to make these huge investments is based on theoretical economics of scale – a Gen 8 plant can make 18 x 32-inch, or 8 x 47-inch, or 6 x 55-inch displays from each substrate. Gen 10 plant, on the other hand, will be able to make 8 x 57-inch or 6 x 65-inch displays from each substrate processed. Put simply, time is money, so if you can make more displays at a time, then the unit cost per display for the depreciation cost of the equipment required to make them in the first place becomes less, and the glass can be sold for a cheaper price.

But, very few companies making displays can afford to make the huge investments required to set up these ultra large new facilities. Those that can are hoping to force their competitors out of business, or at least, out of the TV market due to the price competition that they will establish. Whilst this is a normal "market force" development, it is also a huge risk. When a company decides to invest in a Gen 6, 7, 8, 9 or 10 factory, it has to decide at the same time the size of displays that it will manufacture in the future. If the typical market buyers decide that they prefer the 57" display to the 55", then the company that has set up its line to best suit the unpopular size will be at a tremendous and, possibly, financially disastrous disadvantage in terms of production efficiency and product yield.

The unexpected lack of sales of flat panel TVs during the recent football World Cup has led to many FPD companies having high stocks, which, in turn, will result in surplus sales all around. This may benefit the canny buyer, but is this the market sending a message? In particular, if the market simply says 'no' to the need for these huge displays, then the whole of the investment cycle into mega-sized production plants becomes an expensive exercise in futility. We know what happened to the dinosaurs!

Gen 8 substrate is used to create multiple TV size displays

Chris Williams is Network Director at UK Displays & Lighting KTN (Knowledge Transfer Network)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Living with RoHS – the big questions

Q: Where would I get an exemption certificate?

A: There is no such thing. A product is RoHS compliant if the restricted substances are absent – except where an exemption applies. RoHS is a self-declaration directive and, so, certification, third party testing or labelling are not legal requirements. Proving due diligence in your approach is key, however. Therefore, certification to prove compliance is recommended.

Q: What are the latest guidelines on RoHS?

A: The legislation came into force on July 1st this year. The DTI's Government Guidance Notes have also been reissued (June 2006) to take account of the new regulations. Copies of both these documents can be downloaded from www.rohs.gov.uk. You can also visit www.rohs.info for the latest RoHS updates and support.

Q: Is there an update on the use of lead oxide in plasma display panels (PDP)?

A: The lead oxide in plasma display panels (PDPs) and surface conduction electron emitter displays (SEDs) have been added to the exemptions list. The bus electrode, the black stripe, the address electrode, the barrier ribs, the seal frit and frit ring, as well as in print pastes, have also been added to the exemptions list. Exemptions are still under review and any already granted are not guaranteed to remain exempt forever. It is crucial to stay vigilant around this issue.

Q: How does RoHS affect RFID chips and security tags?

A: Both RFID chips and security tags fall within scope of the RoHS directive. As the stock control and retail security chips and tags are normally attached to another product, they are considered products in their own right. As such, they have to be compliant.

Q: Can I import non-RoHS compliant parts and products for own use?

A: No, the EC's '*Guide to the implementation of directives based on the New Approach and the Global Approach*' (the 'blue book' – available at http://ec.europa.eu/enterprise/newapproach/legislation/guide/index.htm) states: "Imports for own use are also considered placed on the market". So, in the eyes of NWML: EEE imported into the EU for own use – even from another branch of the same organisation located outside the EU – must comply. However, you may use non-compliant parts if you are manufacturing for own use. This is because products that are built for own use are generally not considered as being placed on the 'market' and, therefore, not in the scope of RoHS.

Q: How do servers and network infrastructures fit into RoHS?

A: Servers and networks certainly fall under the RoHS directive. Although there is an exemption in place for the lead in solder for servers and network infrastructures, it is important to remember that lead used elsewhere in the product (i.e. lead solder in ancillary devices and limits on other restricted materials) still have to be RoHS compliant.

Q: How do I deal with NWML, should they tap on my door?

A: This is a question that is asked quite a lot and my answer is that it is essential to keep on the right side of NWML. You should do this by being able to prove due diligence in your compliancy.
For those struggling with RoHS, the NWML sees its main role, at this stage, to assist rather than police. As such, they are approachable for information and advice. Although, it states: "We will help those that are aiming to comply and pursue vigorously those that intend to flout compliance". You have been warned!

Q: Is a thermal imaging camera Category 3?

A: Thermal imaging cameras could be in Category 3 (Information Technology and Telecommunications Products) or Category 9 (which is not currently within scope, but under review). As products can't be in two categories, the main function is the deciding factor. If the main function is considered to be 'measurement of temperature' and the image is of secondary importance, then it is in Category 9. But, if obtaining an image is of primary importance then it is in Category 3. While the instruments clearly do provide images, the image is always accompanied with a temperature colour key, providing measurement information. Assuming that knowing this temperature information is crucial to the function and usefulness of the product, it should be classified as Category 9 not 3.

Gary Nevison is chairman of the AFDEC RoHS team, board director at Electronics Yorkshire and head of product market strategy at Farnell InOne. As such he is our industry expert who will try and answer any questions that you might have relating to the issues of RoHS and WEEE. Your questions will be published together with Gary's answers in the following issues of Electronics World. Please email your questions to EWeditor@nexusmedia.com, marking them as RoHS or WEEE.

Book Review

How Computers Do Math

Clive "Max" Maxfield and Alvin Brown

Wiley-Interscience

The cover of this book modestly tells us in small print that it includes a CD-ROM. In fact, the CD provides a complete software development system for a fictitious computer, comprising a text editor, a symbolic assembler, an execution simulator and debugging facilities (for Microsoft Windows 2000, ME, XP home or pro, but not for Linux or a Mac). The simulation includes a calculator keyboard for input and single-line display for output.

The book explains, from first principles, not just how computers do integer arithmetic, but also everything else that you need to know to program the computer as a calculator. It contains seven chapters, followed by hands-on 'labs' (interactive laboratories), which account for over half of the book and four appendices. A lot of detail is in the labs rather than in the chapters, so it's best to do (or at least to read) the laboratory work for each chapter, before moving on to the next chapter, using two bookmarks.

The opening chapter sets the style by telling us 'why this book is so cool'. The next two chapters take us through binary and hexadecimal numbers and the components of the computer and the calculator interface, respectively. The next chapter introduces some of the computer's instructions, taking us up to subroutines, using the stack for links and parameters.

Chapter 4 starts with the addition and subtraction of unsigned then signed binary integers, including the distinction between the Carry and Overflow flags. Both authors live in the US (hence the American spelling of the book's title) but they have English background, so they remind us here of both the American and English ways of 'borrowing' in decimal subtraction. There is a clear explanation of complement numbers of two, especially "the sign bit is now used to represent –128, meanwhile the remaining seven bits continue to represent their original positive quantities". Signed multiplication is performed using the shift-and-add method (although there is no mention of Booth's algorithm, which avoids the need to treat the signs specially). Likewise, signed division uses shift-and-subtract and there is a comprehensive section on the many possible ways of rounding the result (slightly spoilt by the suggestion that a right-shift is the same as dividing by two: which is only true for 'floor' rounding).

The corresponding labs demonstrate these arithmetic routines and invite us to test them using hexadecimal input and output. The next chapter shows us how to do decimal input and output, complete with leading-zero suppression, and brings everything together as a complete working four-function integer calculator. The final chapter suggests future projects.

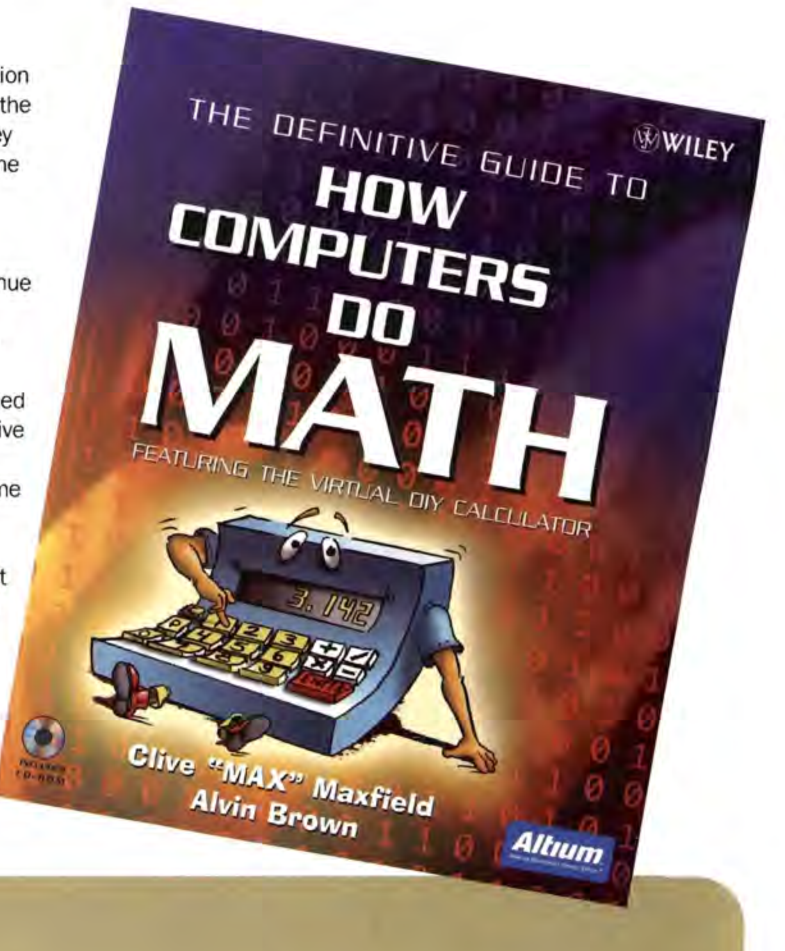
As well as the usual chapter-heading quotations, there are panels dotted around the text, giving the history of various mathematical symbols and terminology. For example, using the asterisk for multiplication (which I assumed was an invention of the computer era), in fact, dates back to 1659. There's also a 77-page 'History of Calculators, Computers and Other Stuff' on the CD.

Anyone buying the book by its title alone could be disappointed, because Chapter 4 on integer arithmetic is all you get about 'math'. Chapter 6 promises floating-point routines on the website, but this is no substitute for a tutorial explanation of guard, round and sticky bits of denormalised numbers and of the Pentium division bug. Likewise, it would be interesting to have been shown how to implement trigonometric functions efficiently, on processors without multiply or divide, as well as on more powerful computers.

On the other hand, this book and CD make an excellent introduction to assembly code programming and will, no doubt, find their way onto the reading list of first year computer science courses. To support this, there is an 'Educators' folder on the CD, containing the labs in PDF format and as Powerpoint presentations.

The simulator lets you to try programming, without tackling the complexity of a modern machine or operating system, without the risk of crashing your computer and without buying a real development kit. The simulated computer is deliberately far from powerful. With just a 16-bit program counter, stack pointer and index register, and a single 8-bit data register, it is slightly less powerful than a mid-1970s Motorola 6800 (with two data registers).

The reader is assumed to be computer literate to the extent of being familiar with, say, Notepad, so only limited guidance is given on using the text editor. An irritation here was that I like to hit the tab key once between the label, function, address and comment columns, to format them quickly and neatly, but the tabs in this editor are set too closely for this to work.



The symbolic assembler is quite powerful. It uses a slightly tedious but logical syntax for address modes (the default is immediate rather than direct), and it stops on the first error, but that's quite acceptable. I was puzzled why I was not allowed to put a label on a line by itself. When I'm jumping past some code, I want to put a label at the end of that code (rather than using the name of whatever comes next, which is bad for maintenance).

Tutors might need some means of getting data into and results from their students' programs. The simulator (in common with much modern interactive software) currently lacks this; even Babbage designed a printer to avoid hand-transcription errors. And if I were giving a course based on this book, I'd place more emphasis on making the finished code robust, at least regarding buffer overrun.

In summary, this book is a light-hearted but thorough introduction to assembler programming. The reader is warned where appropriate that "this isn't quite true", "this is arbitrary" or "other systems do this differently". A lot of thought has gone into the diagrams, which are excellent throughout and I enjoyed working my way through the hands-on labs, which certainly bring what is a potentially dry subject to life.

Terry Froggatt

BOOK DRAW WINNERS

In our May issue of Electronics World magazine, we invited you to participate in a book draw. The winners of the draw are:

'Engineering the World – Stories from the First 75 Years of Texas Instruments'
Alberto Lobina – Italy

'Antenna Toolkit' by Joe Carr
Stein Isaksen – Norway
John Lawrence – New Zealand
Hans C. W. Jespersen – Denmark

'Self on Audio' by Douglas Self:
Mark Shuttleworth – UK
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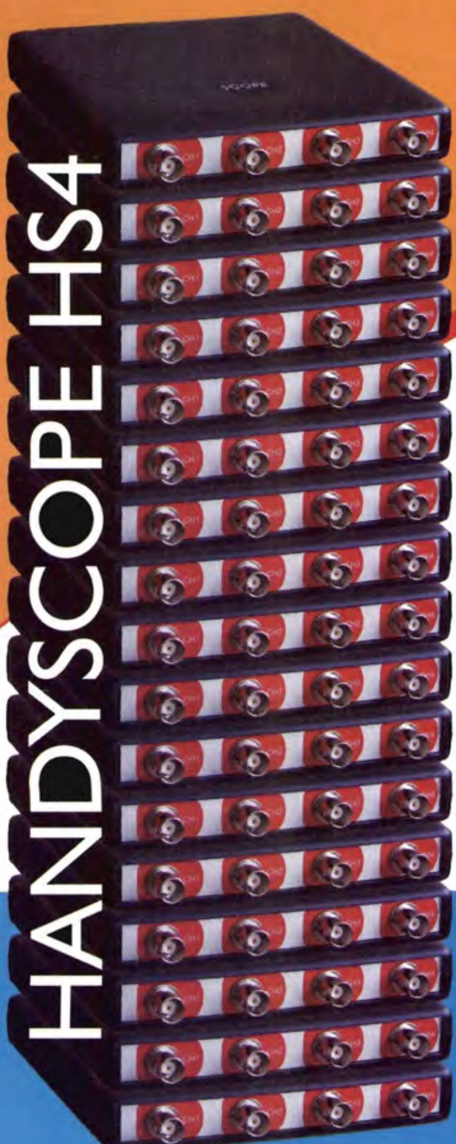

The Handyscope HS4 starts a new standard for multi channel measuring.

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Optical Ring Oscillator Sensor for Light Detection and Measurement

Ring oscillators are widely used in integrated circuits for clock generation and system calibration. Chip manufacturers routinely characterise new fabrication technologies by making ring oscillators and measuring their oscillation frequencies. This provides direct information about the propagation delay times of inverter circuits that form the basic building blocks of digital circuit families.

A simple ring oscillator is formed by a series connection of an odd number of inverters with the output of the last stage feeding the input of the first. The output is tapped from the feedback path and may be buffered for better clock performance. Unlike resonant and relaxation oscillators, ring oscillators can provide multi-phase clock waveforms with each clock derived from the output of an individual inverter and differing in phase from the output of an adjacent inverter by a fixed amount. The frequency, f, of the square waveform generated by a ring oscillator is given by the expression: $f = 1/(2Nt_{pd})$

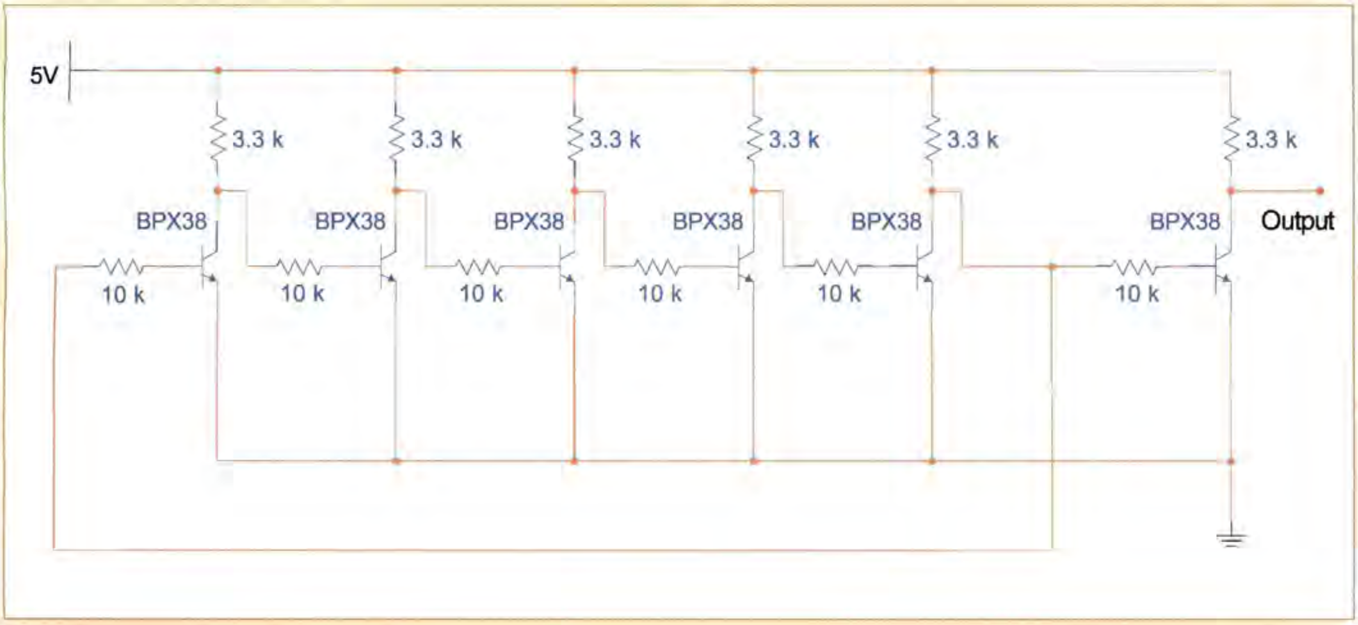
In this formula, N is the number of inverters in the ring oscillator chain and t_{pd} is the propagation delay time of the inverters used. Here, an optically-enabled ring oscillator is described that can be conveniently used for detecting light and, possibly, for measuring very small changes in light intensity.

The optical ring oscillator circuit is shown in the figure below and consists of five resistively loaded bipolar inverter stages. The phototransistor is type BPX38 from Siemens Microelectronics. An additional transistor stage, external to the ring, is used as a buffer stage to improve the output waveform and provide drive current buffering. BPX38 is a medium-gain NPN silicon phototransistor, housed in a TO18 metal can package with an integral flat lens. It has a wide acceptance angle of 80 degrees that makes free space coupling easy. Also, this transistor has a room temperature dark current of about 300nA.

One of the ring transistors is made to accept light while the others are blocked with, say, black paint on their lenses. When powered up, the circuit oscillates and produces a square wave with a duty cycle that is sensitive to small changes in light intensity. Two identical circuits can be built with one used as a dark reference. A phase locked loop could then be used to accurately measure the phase difference between the two channels.

With a 655nm red semiconductor laser diode illumination, maximum clock phase shift of one full time period could be induced at incident light intensities of less than 50 microwatts. For larger changes in light intensity, the oscillation frequency itself is variable and will indicate the presence or absence of light.

Faiz Rahman
UK



Desktop Calendar

The program presented here serves the user in two ways. Firstly, it prints the calendar of a desired month of any year after first AD. Secondly, it lets the user know the day on which a specified date falls in a calendar month. In short, this serves as a complete desktop calendar.

The program works based on a simple logic, where it works on the assumption that the first day of January of the first year AD was a Sunday. It consists of two more functions 'tellday' and 'days' other than the function 'main'. The former determines the number of days in the specified month of a year. The latter finds use in the second task of the program, which is to determine the day on the specified date. The above two functions are called by the function 'main' as and when required.

To accomplish the task of printing the calendar of a month, the program prints the number one until the last day of the month of a year, in an order on the screen. The number is listed beneath a row of the days printed. To start with, in the second row, the program leaves a number of spaces and then prints the numbers. Based on the month and year, it decides the number of spaces to leave in the second row before printing the numbers. For example, if in a particular month the first day falls on a Wednesday, the program leaves three spaces in the succeeding row of the first row and then prints the numbers. After every seventh character, including the initial spaces printed in a row, the program shifts to printing the continuation of numbers in the next row.

The other important task of the program, which is to print the day on which a given date falls, is to a large extent based on the logic used in the above operation. The program uses another function 'tellday' in addition to the above logic for this operation.

The program can serve as a complete calendar for people working on a computer in the office or at home. The same program, with only a few modifications, can print the calendar of one whole year rather than of a single month.

Dhirender Singh
TKR Institute Of Technology, Hyderabad, India

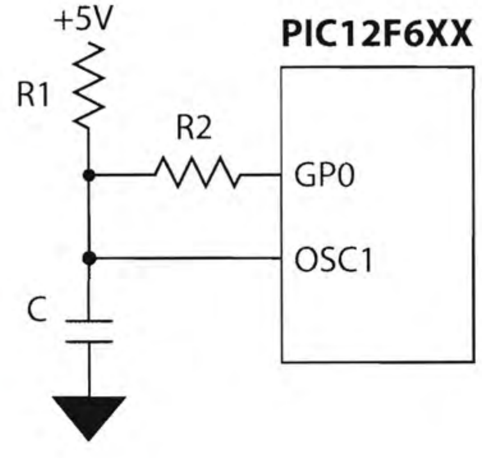
Program Code In 'C' Language

```
# include<stdio.h>
# include<conio.h>

int days(int m,int y)                /*calculates the number of days in the month*/
{
int j;
if(m==1||m==3||m==5||m==7||m==8||m==10||m==12)
j=31;
else if(m==2 && y%4==0)              /*checking for the leap year*/
j=29;
else if(m==2 && y%4!=0)
j=28;
else
j=30;
return j;           /*returns the number of days in the month*/
}

void tellday(int z)          /*prints the day based on the input from main function*/
{
printf("\n\t\t\t\t  ");
if(z==1)
printf(" ITS SUNDAY");
else if(z==2)
printf(" ITS MONDAY");
else if(z==3)
printf(" ITS TUESDAY");
else if(z==4)
printf(" ITS WEDNESDAY");
else if(z==5)
printf(" ITS THURSDAY");
else if(z==6)
printf(" ITS FRIDAY");
```

```
else
printf(" ITS SATURDAY");
}

void main()
{
int m,j,k,y,z,s=5,a,b,v,x,day;
clrscr();
printf("\n\t\t\t\t CALENDAR.C");
printf("\n\n\n\n ENTER THE MONTH ");
scanf("%d",&m);
if(m>12)
{
printf("\n\t\t INVALID DATA ENTRY! TRY ANOTHER VALUE.");
delay(5000);
exit(0);
}
printf("\n ENTER THE YEAR ");
scanf("%d",&y);
for(x=1;x<=y;x++)                    /*determines the number of spaces after first Sunday*/
{
if((x-1)%4==0)              /*checks if previous year was a leap year*/
s=s+2;
else
s=s+1;
if(s>=7)
s=s-7;
}
for(a=1;a<m;a++)
{
b=days(a,y);
s=7-(35-b-s);
if(s>=7)
s=s-7;
}
printf("\n\t\t\t\t\t%d/%d",m,y);
printf("\n\t\t\t****************************************");
printf("\n\t\t\t SUN  MON  TUE  WED  THU  FRI  SAT");
printf("\n\t\t\t****************************************");
printf("\n\t\t\t");
for(z=1;z<=s;z++)                    /*based on above calculation prints the spaces*/
{
printf("     ");
}
v=days(m,y);
for(k=1;k<=v;k++)                    /*prints the numbers starting from '1' after the spaces*/
{
printf("%5d",k);
if((k+s)%7==0)
printf("\n\t\t\t");
}
printf("\n\n\n\t\t\t\t ENTER THE DAY: ");
scanf("%d",&day);
for(k=0,z=0;k<=s;k++)                /*determines the input for "tellday" function*/
z++;
for(k=1;k<day;k++)
{
z++;
if(z>7)
z=z-7;
}
tellday(z);
getch( );
}
```

8-pin FLASH PICmicro Microcontrollers

TIP 1: DUAL SPEED RC OSCILLATOR



1. After reset I/O pin is High-Z
2. Output '1' on I/O pin
3. R1, R2 and C determine OSC frequency
4. Also works with additional capacitors

The frequency of the PIC MCU in external RC oscillator mode depends on resistance and capacitance on OSC1 pin. Resistance is changed by the output voltage on GP0. GP0 output '1' puts R2 in parallel with R1 reduces OSC1 resistance and increases OSC1 frequency. GP0 as an input increases the OSC1 resistance by minimising the current flow through R2, and decreases frequency and power consumption.

Summary:
GP0 = Input: Slow speed for low current
GP0 = Output high: High speed for fast processing

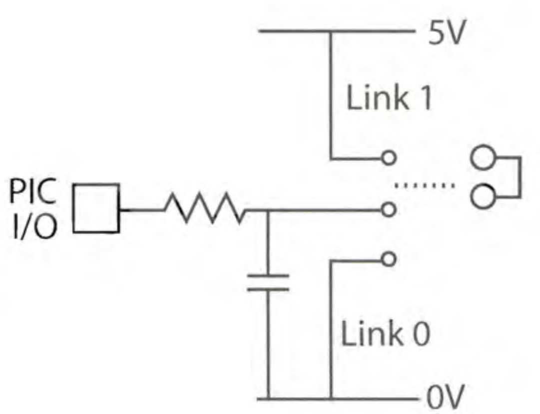
TIP 2: READ THREE STATES FROM ONE PIN

To check state Z:
- Drive output pin high
- Set to Input
- Read 1
- Drive output pin low
- Set to Input
- Read 0

To check state 0:
- Read 0 on pin

To check state 1:
- Read 1 on pin

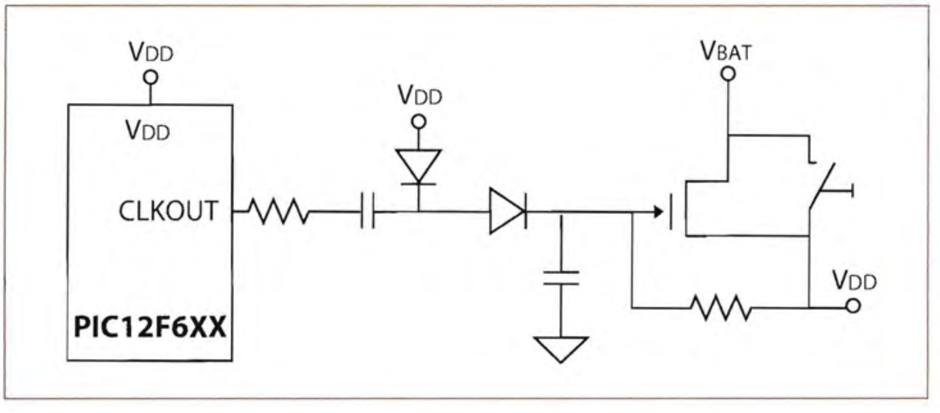
State	Link0	Link1
0	closed	open
1	open	closed
NC	open	open



Jumper has three possible states: not connected, link 1 and link 0. The capacitor will charge and discharge depending on the I/O output voltage allowing the "not connected" state. Software should check the "not connected" state first by driving I/O high, reading 1 and driving I/O low and reading 0. The "Link 1" and "Link 0" states are read directly.

TIP 3: VDD SELF-STARTING CIRCUIT

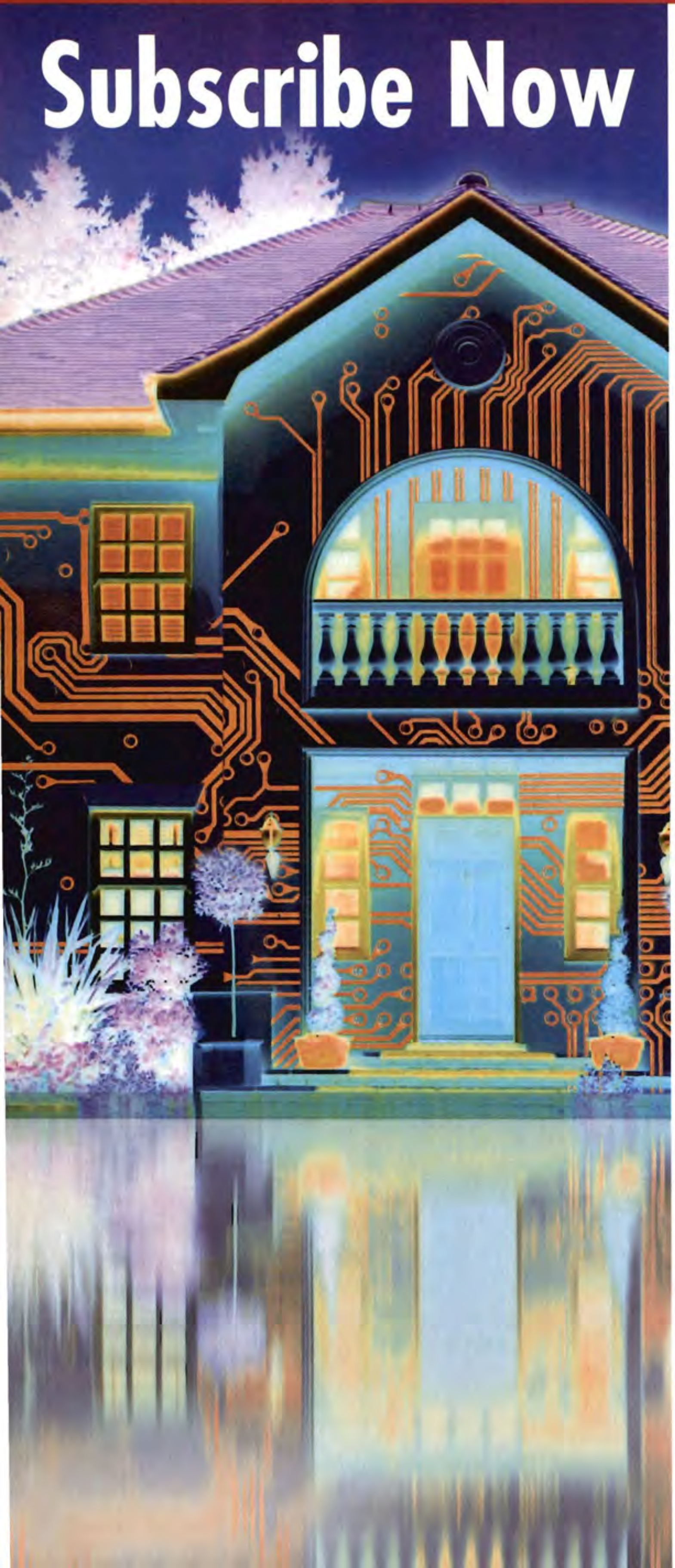
Building on the previous topic, the same charge pump can be used by the MCU to supply its own VDD. Before the switch is pressed, VBAT has power and the VDD points are connected together but unpowered. When the button is pressed, power is supplied to VDD and the MCU's CLKOUT (in external RC oscillator mode) begins to toggle. The voltage generated by the charge pump turns on the FET, allowing VDD to remain powered. To power down the MCU, execute a SLEEP instruction. This allows the MCU to switch off its power source via software.



Advantages:

- PIC MCU leakage current nearly 0
- Low cost (uses n-channel FET)
- Reliable
- No additional I/O pins required

TELEVISION



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Step-Down Regulator in TSOT-23

Now available from Monolithic Power Systems (MPS) is the MP2359, a 1A non-synchronous step-down regulator with a wide 4.5-24V input voltage range. This device provides one of the smallest solution footprints around by integrating a 350mΩ power switch, 1.4MHz PWM oscillator, boost diode and loop compensation. A complete solution requires just seven external components.

Consuming just 0.8mA of supply current, the MP2359 achieves an operating efficiency greater than 90%. The output voltage is adjustable between 0.8V and 15V to meet current and future voltage requirements. The device is offered in a compact TSOT-23 package.

Additional features of the MP2359 include cycle-by-cycle current limit, under voltage lockout and thermal shutdown.

The MP2359 is ideally suited for space-constrained applications, operating from poorly regulated AC/DC converters or multi-cell batteries.

Samples and evaluation boards are in stock now. Pricing for the MP2359 begins at $1.20 in 1K piece quantities.

www.toshiba-components.com

New Connector Lines From Tyco

Following the recent introduction of the 25 and 37 position connector sizes, Tyco Electronics now offers a complete range of D-Sub connectors for surface mounting.

Large die-cast mounting brackets at the rear of the connector provide a controlled centre of gravity for stable positioning and ensure outstanding mechanical retention and electrical grounding.

Fully pick-and-place capable without force, the connector may be processed efficiently with standard surface mount techniques. A low 3.6mm mounting height and short front to back footprint allow maximum density around the connector.

Available in 9- to 37-position plug and socket variants, the connectors feature steel, tin-plated front shells with black UL 94V-0 thermoplastic housings and 0.80μm gold-plated contacts. Hardware options include 4-40 or M3 threaded inserts or screw locks, or plain 3.1mm hole. All materials are compliant with the RoHS (Restriction of use of certain Hazardous Substances) directive.

Quad LC Adapter Doubles Fibre Count

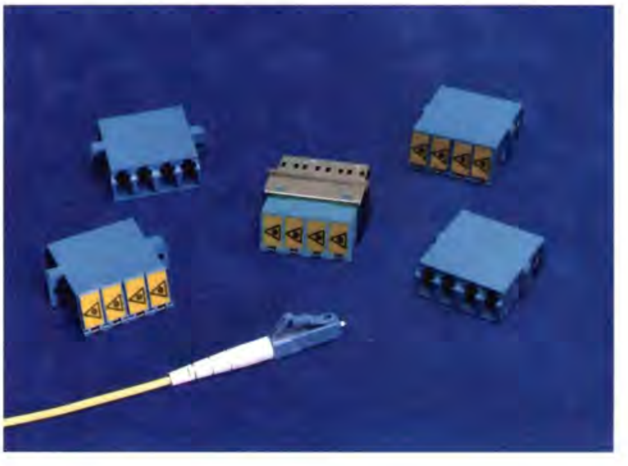
To accommodate the need for increased fibre quantities in high-density applications, Molex has added the Quad LC Adapter to its small form-factor product family. This four-position LC adapter solution provides multiple connection options from a single adapter, offering a robust solution for high-density applications such as hubs, servers, routers and other telecommunications equipment, optical DVI, storage and Local Area Networks (LAN).

Available in either snap-mount or screw-mount installation styles, the Quad LC Adapter allows for installation flexibility while providing increased density over using multiple simplex or duplex LC adapters.

The adapter also features optional individual shutters on the user side, to help provide an eye-safety option for protection, even when the adapter is not fully populated. It is offered with either Phosphor Bronze or Zirconia Ceramic alignment sleeves to accommodate single mode, multimode or Angle Polish Connectors (APC).

Connection options for the Quad LC Adapter include four simplex LC connectors, two simplex and one duplex LC connector, or two duplex LC connectors. Mounting dimensions are identical to the duplex SC adapter and can be used as a direct drop-in replacement for density upgrade.

www.molex.com/product/fiber



The MathWorks Links to TI's Code Composer Studio

The MathWorks and Texas Instruments (TI) announced the release of Link for Code Composer Studio (CCS) Development Tools 2, which now enables developers using embedded systems with TI's DSPs to perform continuous testing and verification of their code. TI's CCS software is a fully integrated development environment (IDE).

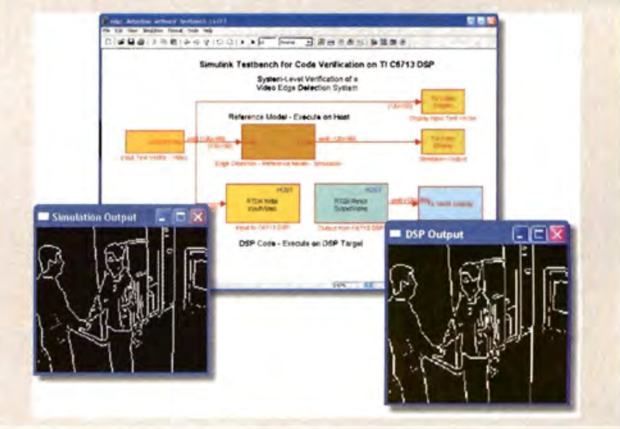
"Model-based design calls for the same model to flow through the four major stages of the software development process, from modelling to simulation to code generation to code verification," said Arun Mulpur, technical marketing manager for signal processing and communications at The MathWorks. "In embedded signal processing systems, more and more implementations involve both hardware and software components. Now with Link for Code Composer Studio, engineers can verify designs for a software component like an ARM or a DSP or a hardware component like an FPGA or an ASIC, using the same test bench environment, which automates and accelerates code verification and validation."

Developers using Link for CCS 2 can construct test benches directly in Simulink using Real-Time Data eXchange, as well as MATLAB.

The MathWorks is in discussion with other vendors with IDEs over the Link. "More and more designers want platform-independent designs," added Mulpur.

www.mathworks.com/products/ccslink.

www.ti.com.



Dataman's Programmers Offer USB2

The growing popularity of notebook PCs and the absence of the parallel interface (LPT port), even on desktop PCs, is the reason for the expansion of Dataman's portfolio of programmers connectable to a PC through the USB port. Dataman's new range of programmers are controlled by a status automat, based on a powerful FPGA circuit, which supports communication with a PC through full speed USB 2.0 interface and offer fast programming of circuits.

The Dataman-40Pro target segment is for the engineer who requires a low cost, small, fast and portable programmer. The design is to support a wide range of memory and logic devices. The basis of the hardware is a 40-pin versatile pin driver and freely programmable voltage generators, as well as the limitation of the logical high level, which allows support for the latest low voltage chips. It is ideal for the engineer on-the-move who needs to set up his working environment quickly in a small space.

The series also includes the Dataman 48Pro programmer and the Dataman-448Pro, which is designed for the high volume production environment with minimal operator effort. It features four independent universal programming modules with support for over 22,000 devices.

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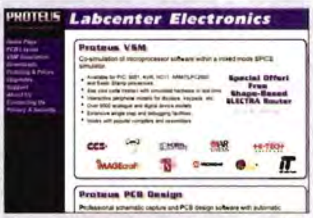

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