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ELECTRONICS WORLD

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- THE DOS AND DON'TS OF BUYING AN INDUSTRIAL ROBOT

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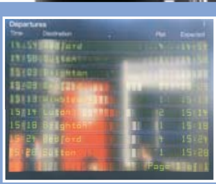
NEW FPGA FABRIC CREATES FASTER DEVICES



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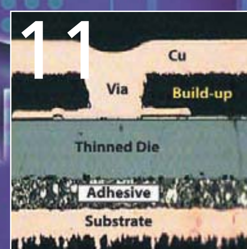

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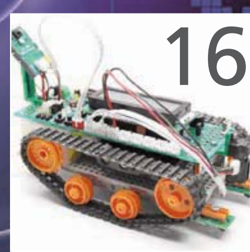
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FEATURES

ELECTRONICS WORLD

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Electronics World and You

Dear Readers,

Electronics World has been evolving over the past years and we'd like to hear your comments on how we are doing. Although we've tried to align the magazine to the needs of engineers employed in the field of electronics, we have also kept some elements that those interested in electronic projects outside the work environment may enjoy.

We've been running regular features from a well-known professor and author – Dogan Ibrahim; we've started new and different series of articles, including those on the subject of microcontrollers and microcontroller-related projects; as well as developed a comprehensive new website – which by the way, also carries on to evolve and improve. For example, on our website (**www.electronicsworld.com**), you can pick up some of the articles that have recently featured in the magazine (but not all, since many are exclusive to the print version); you can read the daily section on the latest technology developments and achievements in the world of electronics; but also buy articles that you'd like to keep for your records as well as buy whole issues of the magazine in digital format.

In addition, we have started to build a digital archive of old copies of Electronics World, which will allow you to search old material and find individual articles on any electronics-related subject.

For the future, we are thinking of introducing articles from some of your old favourites, such as Ivor Catt for example, who is still pondering the unresolved issue of "The Catt Question".

To complement these developments we will create updates via emails (this is optional, of course), so if you are interested in receiving regular updates from us relating to the magazine and the website, please send us your email addresses so we can add you to this service.

So, as we are trying to move on the Electronics World magazine and website, we are hoping that you'd like to participate in the shaping of these too.

Traditionally, Electronics World readers have been very interactive, communicating their needs, wishes, praises and, indeed, complaints to us. As such we thought that at this point in time it is the perfect opportunity for you to tell us what you'd like to see more of in the magazine but also on the website too, as we'd like to cater for your exact needs.

Indeed we do have many ideas ourselves that we will continue to implement, but to make the magazine and website your first port of call, we will need your input.

We would like to hear your ideas of what do you think will help you at your work, with your projects or you'd simply like to see more of. So, go on, put your thinking caps on and email those ideas to **svetlana.josifovska@stjohnpatrick.com**

Editor
Svetlana Josifovska

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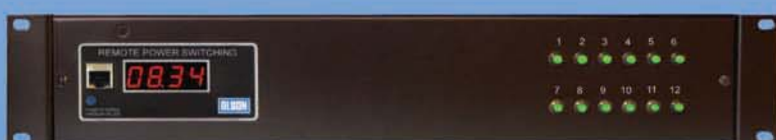

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NEW FPGA FABRIC MAKES FASTER DEVICES

A semiconductor start-up which two years ago launched a 2GHz FPGAs has now gone slower with a 1.5GHz device. "We found out that's what the market wants," said John Holt, co-founder and CEO of US-based Achronix Semiconductor.

Even at 1.5%GHz, the device is still much faster than existing FPGAs, but also consumes less power – the 'holy grail' for all those designers who want to use an FPGA but find them power-hungry and cumbersome.

Achronix's FPGAs are of the traditional type: SRAM-based 4-LUT (look up table) registers, a flip-flop and I/O. However, the firm has broken down the path for the data – the pipeline – with receive/transmit elements (which it has named picoPIPE pipeline elements) in between each logic, where the data, instead of being governed by a global clock synchronously, moves around asynchronously and the trigger is an acknowledge signal from the picoPIPE element in front.

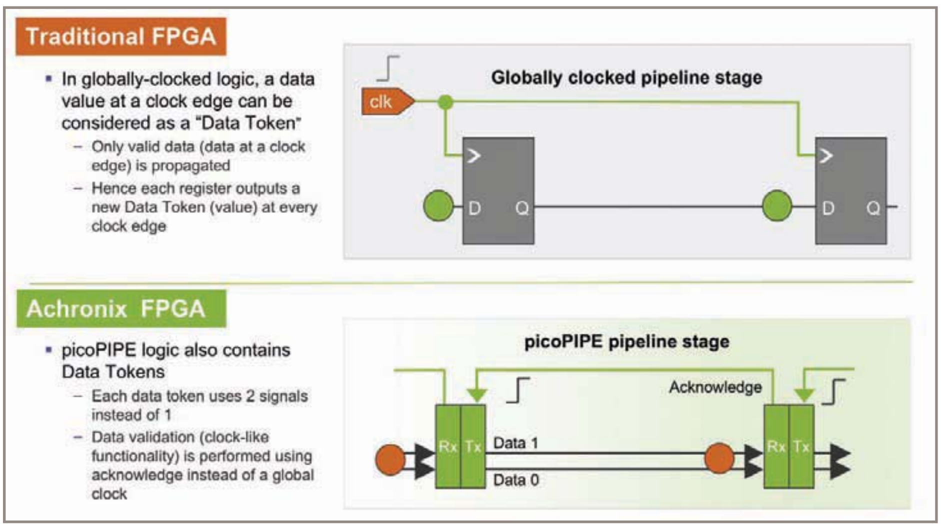
As such, each data value uses two signals (data valid and acknowledge) to send acknowledgements to and fro (handshake), unlike in traditional architectures where there's only the one signal, which moves forth through the pipeline. Achronix's set-up shortens the time with which data propagates through the device. Whereas in traditional FPGA fabric, the data will need to move from the beginning to the end of the fabric before a new data value is triggered, in Achronix's version, a new data value can be sent straight after the previous one has reached the first picoPIPE element in the pipeline.

"We only have one level of logic for the data to go through," added Holt.

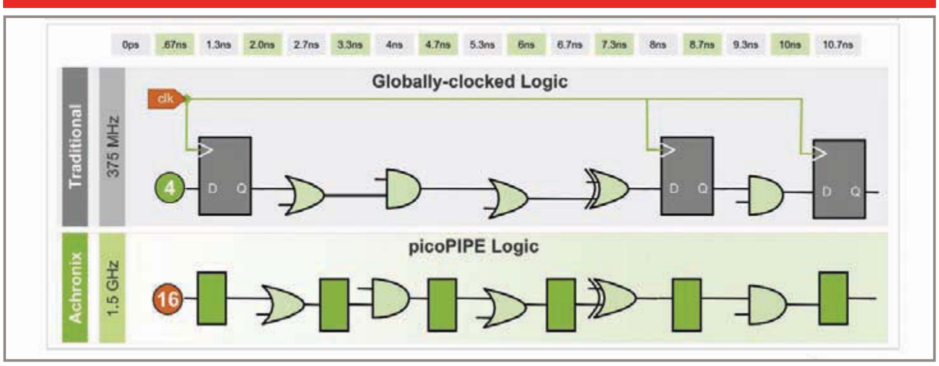
Achronix now has the Speedster family of FPGAs based on this fabric, which vary in package sizes and resources, such as memory, multipliers and picoPIPE elements among others.

Achronix's target markets for its devices are in telecoms, networking, security and encryption, high-performance computing and others.

A development kit is also available.



Above and below: Comparisons between a traditional FPGA and that of Acrhonix



■ European electronics manufacturer Exception PCB has set up a four-year research partnership with two UK universities – Edinburgh's Heriot-Watt and London's Greenwich University.

Two graduate students will be funded to support Exception's research into the megasonic plating process – an area of innovation for printed circuit board (PCB) manufacturers. The students will work with standard chemistry and utilise custom plating baths with transducers, to enable micro-vias and blind-vias of varying diameters and depths to be plated.

This will enable Exception to develop new technologies that support high density interconnect (HDI) solutions.

■ EU governments are planning to work together to better enforce the RoHS regulations in Europe that ban hazardous substances from electrical and other household and commercial products.

Since RoHS laws came into effect in July 2006, governments have been criticised for a lack of effective monitoring to enforce compliance with the laws, which led to some companies to continue selling products with hazardous substances over allowable limits.

Government bodies across Europe now plan to improve the effectiveness of their RoHS monitoring and resources by adopting a cross-border model, following successful efforts by the Nordic countries, which united their RoHS programmes and increased the depth of monitoring and reporting of non-compliances by sharing cross-border data.

■ A new system pioneered at Aston Business School is set to save businesses time and money by avoiding the design and production of unnecessary components. The online research system called CADFind (**www.sketchandsearch.com**) has been described as "the graphical Google for engineers" and allows electronic searches to be made for drawings, rather than by the words that describe them.

Dr Doug Love, who leads the development of CADFind said: "The system allows searching for drawings of products or components that already exist within files or workshops. We have developed this system because engineers continually re-design the same or very similar components as there is no way of knowing what their predecessors or colleagues have produced in the past."

A Dozen ROBOT Dos And Don'ts

AT FIRST GLANCE, industrial robot specification sheets look fairly straightforward. Typically, there's a picture of the particular model, looking sleek and stylish, unblemished by external cabling, end-of-arm tooling, feed mechanisms and safety guards.

Then there are the quoted figures: number of axes, maximum payload, reach, repeatability, maximum speed, cycle time and installation footprint. All these specifications seem comparable, manufacturer to manufacturer, so it's like buying a car or a TV, surely.

Actually, it's not. During my many years designing and commissioning robot workcells, I've encountered many mistakes and oversights when specifying a robot for a particular task. Some I made myself, in the early days when robotics was still an unfamiliar technology, most I had to fix for frustrated robot buyers, whose machines wouldn't do what they were supposed to do. So I have assembled a dozen of the most common "robot dos and don'ts", partly to help those new to robotics avoid the worst pitfalls, but mainly to emphasise that specifying and building robot workcells is a specialist job, best left to specialists. It's what I do.

1. Don't overestimate speed performance

Although manufacturers' speed data is usually honest, a robot won't operate at full speed throughout its work cycle, nor will it interact with the workpiece at maximum speed. You also need to allow for the gripper to secure and release the workpiece, which slows the cycle time. True, some manufacturers do quote cycle times, based on a benchmark function, but this relates to a simple pick and place operation, not necessarily your application.

The only way to get an accurate estimate of speeds and cycle times is to pre-design an actual workcell simulation, which I'll come to later.

2. Do make allowances for the end-effector

The end-effector is the end of arm tooling that grips the workpiece, usually by means of grippers, suction or magnetics. The gripper or vacuum cup needs to pick up the workpiece with sufficient force for the weight of the object, but without too much aggression that it marks or damages the object. You also need to take into account the robot's acceleration forces during a high speed work cycle, which can actually lever open grippers or peel the workpiece straight off the vacuum cup. The weight of the end-effector, together with its cable or hose, needs to be added into the equation, when specifying the machine, which leads to Tip 3.

Robot articulation

3. Don't underestimate payload requirements

A common specifying error is to omit the weight of the end-effector and associated cabling when calculating payload. A robotic gripper, which employs jaws or fingers to hold the workpiece, can weigh several kilos, which is why lighter vacuum cups are often specified, although they require vacuum generators and hose that must also be factored into the payload. Kinetic forces generated by off-centre payloads, as well as torsional forces created at the extreme end of the robot arm's travel, should also be accommodated in your calculations. Remember too that the maximum payload is just that, an occasional maximum limit, not the normal operating capacity.

4. Do take the robot arm into account

If you've ever played snooker in a room that was too small or tried to saw wood tight against a wall, you'll appreciate what I mean. A robot, especially a 6-axis articulated robot, has an arm mechanism very similar to a human arm, complete with jointed elbow. It has a large work envelope, almost spherical in shape, and the end-effector can be manipulated to any position or orientation within that envelope. However, when laying out the workcell, many people focus solely on the end-effector, forgetting the rest of the arm and particularly that flying elbow. Given the speed of movement, there is great potential for mechanical damage if the rest of the arm is overlooked.

5. Don't overlook cable management

Cable management is a major installation issue that's often forgotten. Although it is possible to channel cables and pneumatic hose internally through the robot base and arm, in most cases some level of external cable routing is required. Here, the very flexibility of the robot arm and its high speed movement pose a problem, since you need to plan the cable routing to avoid snagging, tangling and stressing sensitive connecting wires. Designing cable runs to allow unrestricted movement of the robot manipulator is quite an art and happily there are flexible cable carrying systems available, which are able to withstand the twisting movement, high-speed friction, and harsh operating environments associated with such applications.

6. Do provide for operating conditions

The conditions in which the robot will be operating, whether it's a dusty, greasy shop floor or a pristine cleanroom environment, is an important consideration when specifying the IP rating, or ingress protection. Levels of protection extend from a basic IP54, through the more standard water- and dust-tight IP65, which is ideal when installing next to a machine or workstation, through to special versions equipped with gaiters and external coverings for laboratory, cleanroom paintshop or hazardous applications. Enhancing the IP rating adds to the cost, so consider the application carefully; just because it's food processing, the robot might be handling product that is already wrapped, so advancing the spec may not be necessary.

7. Don't forget workcell safeguarding

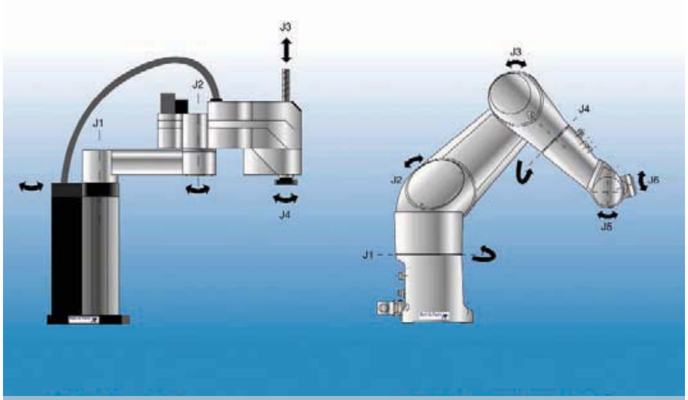
Often overlooked in the initial specifying and costing, yet absolutely critical from a safety compliance angle, are the mechanical and electronic safeguards. Robots are virtually silent and extremely fast in operation and unlike conventional automated machinery, in which the operating envelope is clearly defined, most robotic workcells are individual in configuration, so bespoke safeguarding is usually required. HSE guidelines provide standards for perimeter fencing, interlocking devices, opto-electronic systems, safety light curtains and emergency stop actuators, which we adhere to when building highly sophisticated workcell safeguarding.

8. Do factor in the peripheral costs

Far be it for me to dissuade potential robot buyers by pointing out hidden costs, because robotic applications can, and usually do, justify themselves on financial grounds alone. But don't overlook peripherals, like teaching pendants, interface boards and software licenses, when budgeting for an installation. Because if you omit these from your initial order, then run over budget and incur delays awaiting delivery, question marks are likely to be raised. Teaching pendants cost a grand or so and you require them for programming purposes, but you don't need one for every machine. Software licenses are often required for every machine and you'll need plug-in cards for network communications, so be sure to compare competitors' pricing.

9. Don't confuse accuracy with repeatability

Repeatability data always looks impressive at ±0.02mm or so and, indeed, it is. But don't confuse accuracy with repeatability and expect the same precision, because repeatability figures are always better than those for accuracy. Repeatability refers to how precisely a robot can return repeatedly to a given position, following the same approach vector. Accuracy relates to how closely a robot can move to a specified X-Y-Z position in the work envelope. If, say, a robot gets to within 0.5mm of that specified position, that would be its accuracy; however, once that position is programmed into the controller memory and, each time the robot is sent there, it returns to within 0.02mm of its taught position, that would be its repeatability.



SCARA robot (4 DOF) *6-axis or Articulated robot (6DOF)*

10. Do exploit the robot's full capabilities

Current trends toward shorter product life cycles and more versatile manufacturing mean that when selecting an industrial robot, it pays to bear in mind possible future duties. Unlike fixed automation, robots offer inherent flexibility and can be re-programmed and redeployed any number of times, over an average 15-year life cycle. Also, modern robots, especially 6-axis models, are capable of so much more than simple pick and place duties, since the arm's ability to reach over and around obstructions and twist or tilt the end-effector make it ideal for complex functions. The extensive command sets embedded into the robot controller and pre-written subroutines also make programming easier and more economical.

11. Don't buy a robot solely on price

The fact that a modern robot costs a quarter what it did a decade ago, means that the technology is already more accessible and affordable. So don't be tempted to buy solely on price, but look instead for best-value performance. The various manufacturers have different strengths in different robot classes, so check out their credentials in the payload capacity you're buying. Equally, it doesn't make financial sense to over-engineer the solution by specifying functionality you don't need. A 6-axis robot is highly capable, for instance, but for many routine pick and place tasks a 4-axis machine would be equally capable and considerably cheaper.

12. Do request a robot workcell simulation

When planning and specifying a new project, we invariably use an advanced 3D design package to simulate the entire workcell and verify that our initial calculations and specifications are correct. In most cases, we use a simulation, not least because it demonstrates graphically to the client that our proposed solution will work. It allows us to check the reachability of all positions, optimise cycle times, and generally observe the dos and don'ts I've covered here.

This month's Top Tips were supplied by Stirling Paatz, of robot integrators Barr & Paatz (www.barr-paatz.co.uk).
If you want to offer your top tips please write to the Editor at Svetlana.josifovska@stjohnpatrick.com

A REVERSAL OF FORTUNE

David Bance of Prism Electronics looks at the changes in outsourcing in electronics manufacturing

THE UK REMAINS a power house of new electronic product design. The large vertically-integrated factories may no longer reside within the UK because manufacturing has been outsourced to low-cost regions of the developing world. However, there is still much to be proud of emerging from British OEMs engaged in novel and innovative high-tech electronics design and development work.

There are countless small, highly skilled and creative companies in the UK developing new technologies and bringing to market new and innovative products. Do these smaller OEMs experience the same benefits as large manufacturers when they attempt to outsource the manufacture of their designs to low-cost regions of the world? Anecdotally at least, the answer may be 'no'.

There may be several reasons why smaller OEMs do not experience the levels of benefit they seek from off-shore outsourcing of their electronic manufacture.

- Cost reductions expected from 'off-shoring' have not been realised because the approach adopted in estimating gains has been too simplistic from the outset.
- UK-based OEM customers have experienced higher than anticipated costs associated with supplier management.
- To be truly effective, the supplier must become an extension of the customer's business. Complete integration can best be ensured by the supplier immersing themselves in the customer's company culture and gaining an understanding of the business' requirements, any constraints and what is important to achieve success. It is extremely difficult to do this from the far side of the world.
- Success can be all about communication. This can only be realistically achieved using local solutions because language, time zone, legal and cultural differences – as well as the costs and time involved in getting people together – make overseas partnerships extremely difficult.
- Another major reason for difficulties has been an inability among OEMs to forecast demand accurately. This has frequently resulted in high expediting costs in plugging gaps in forecasts – or lost faith among end customers when the gaps have proved impossible to plug.
- OEMs aiming for the lowest manufacturing cost may only be looking at the bottom line. In doing so that they often overlook other factors including retaining the ability to serve customers rapidly with high-quality products and services.

So, is there an economic and effective alternative to 'off-shoring'? At Prism Electronics we think the answer is 'yes'.

Recent research into successful supply-chain performance emphasises the importance of strong partnerships between customer and supplier operating at multiple levels within the relationship. There appears to be little substitute for the old-fashioned virtues of personal relationships, trust and hard work when developing fulfilling relationships.

In the UK there are thousands of SMEs producing their own electronics products with many sources of design, manufacturing and commercial challenge. There are also many hundreds of contract electronics manufacturing companies with high levels of manufacturing experience and capabilities to call upon. This means that OEMs are likely to find a local partner that has the appropriate skill-set to enable them to rapidly develop their core business.

OEMs want cost-effective solutions that enable them to quickly get their products to market. Effective service providers act as an extension of their customers' business, often with multiple points of personal contact. Partnering with a specialist local contract electronics manufacturer allows smaller OEMs to obtain the high levels of customer service necessary to be successful.

A contract electronics manufacturer partner should be the experienced link that an OEM can rely upon to solve its wider supply and manufacturing problems. Building partnerships requires frequent and transparent communication to build trust in the knowledge that the partnership can be mutually beneficial. Contract electronics manufacturers creating these kinds of partnership can provide engineering support by designing for manufacture, undertaking reliable quality investigation and suggesting cost-effective test strategies. They can also provide purchasing support by managing materials procurement and obsolescence – in addition to handling production and shipping or direct delivery to the customer and after-sales support.

Responsive suppliers such as Prism Electronics can look beyond the initial brief to advise customers on total product life-cycle issues such as prototype and pre-production build trials, monitor forthcoming legislative changes that may have an impact on manufacture and supply, manage obsolescence due to component withdrawals by manufacturers and ultimately oversee product withdrawal. Such suppliers can also independently invest in and economically utilise the latest capital equipment and systems required, such as pick and place machines and production management software.

Ultimately, if the product succeeds, volumes may grow to the point where the cost benefits from off-shore manufacture become compelling. Good contract electronics manufacturers should then be able to support their OEM customers through some form of extended partnership with a manufacturer in a low-cost manufacturing region with which they have already developed a working relationship.■

3-D INTEGRATION BEGINS TO DEFINE ITS FUTURE

By Keith Gurnett and Tom Adams

THE PURPOSE of 3-D integration in electronics assemblies is to reduce the thickness of assemblies, in part to make them fit into thinner appliances such as cell phones, and in part to shorten the interconnect distances between chips in order to improve performance.

To some extent, 3-D integration is also being pushed along by the growing realisation that shrinkage of silicon die in the x and y dimensions is reaching some sort of ultimate limit, or at least a limit that can only be exceeded at unacceptable cost levels.

A few consumer products already use some form of 3-D integration and more are likely to appear in the near future. Depending on its application, the 3-D package may be mounted on a conventional printed circuit board, or may replace the board. Most 3-D designs do not use solder, lead-free or otherwise, and one of the strong attractions of 3-D integration for many assemblers is the opportunity to dispense with solder and its numerous attendant problems.

A great many researchers are now busy developing their own versions of 3-D integration. Among them, there seem to be three more or less distinct types of integration that depend on the structural level at which integration is carried out and the distances between relevant circuits.

- What may be termed integration of packages, exemplified by the Occam Process being promoted by Joe Fjelstad of Verdant Electronics in the US. The Occam Process uses plastic-packaged components and, preferably, chip-scale packages. A package is bonded to a thin, sticky substrate and then overmoulded with a material such as epoxy. Vias are laser-drilled through the substrate to the contact points, and the vias are plated (first electrolessly, then electrolytically) with copper. A resist layer is laid on top of the substrate and traces are formed. The process is repeated to form multiple layers if necessary.
- The Chip-in-Polymer process, developed over many years by Fraunhofer IZM in Berlin. Chip-in-Polymer uses bare die rather than packaged chips. A thinned die is bonded adhesively to a thin core substrate and overmoulded with a resin-coated copper build-up layer. Vias are drilled through the copper and cured layer to the previously modified IC contact pads, and the vias are plated with PCB-compatible copper. A patterned layer of resist is put on top of the copper surface and etching of the copper forms the traces at the surface. The entire assembly may be less than 100 microns thick and multiple assemblies can be laid on top of each other to create products having minimum z-dimensions and high performance.
- The silicon-to-silicon approach, represented by the Through-Silicon Via technology being developed at Georgia Tech (US). In this approach, vias are etched through the die while it is still in wafer form. The vias are plated and will eventually be bonded to a bump on a die lying below the first die. Because of the thermal build-up of the stack, Dr Muhannad Bakir and PhD students Calvin King and Deepak Sekar at Georgia Tech have developed a method for etching horizontal channels into the backside silicon and for etching fluidic microvias through the die. The assembly, therefore, has both through-silicon electrical vias (TSEVs) and through-silicon fluidic vias (TSFVs). The channels and microvias will transport a liquid coolant, which will make it possible to stack items such as high-end processors and run them at high speeds. The first applications will be in servers.

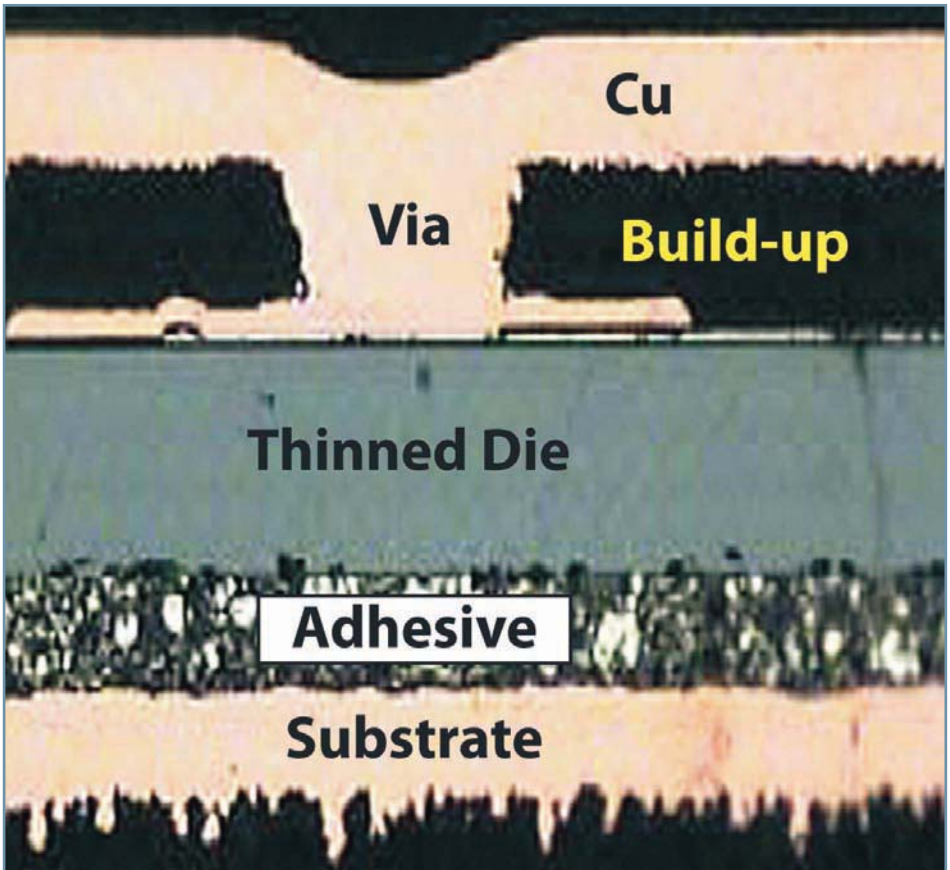


Figure 1: *Cross-section through a Chip-in-Polymer device. Devices tend to be very thin, and can be stacked*

3-D integration as a whole has enjoyed a great deal of publicity in the past year or so. The concept of 3-D integration became the darling of the media, so to speak, and the potential benefits of 3-D integration got ahead of the current reality. For example, many people have the distinct impression that through-silicon vias are already being used in production. As of mid-2008, they are not being used in production. Their first use will almost certainly be in an IBM product scheduled for release in the second half of 2008, and will be something far more sophisticated than a typical consumer product.

In an attempt to peer through the haze of publicity, we asked the three sources above what might be the first consumer-level products for their technology. In a sense this is an unfair question, because whether a particular consumer product is manufactured or not, and whether it is manufactured according to a specific design, is so dependent on multiple decisions involving costs, materials, equipment and the like that trying to predict very far into the future is an uncertain enterprise.

"JOE FJELSTAD HAS FOUND AN UNUSUAL DEGREE OF INTEREST FOR 3-D INTEGRATION IN BRAZIL, APPARENTLY BECAUSE BRAZIL IS A NEWCOMER IN THE WORLD OF ELECTRONIC MANUFACTURING"

Andreas Ostmann, the Fraunhofer coordinator of the Chip-in-Polymer program, has several new projects that are currently being launched and that involve using Chip-in-Polymer in manufacturing. But he is cautious about broad-spectrum predictions. "Always," he explains, "when you change to something new, even if the high-volume costs are comparable, you have to go over a barrier, because you have to invest in new things, while the other technology is already running. The pain with the old technology must be great enough so that you say, OK, now we go to the new one."

The lure of 3-D is great enough that Fraunhofer IZM is currently involved in several projects with industrial partners. One project, involving Bosch and other partners, is developing a 77GHz automotive radar system. The system will use embedded radio frequency chips; one of the overall goals is low manufacturing cost.

Fraunhofer is also working with a semiconductor manufacturer which needs to upgrade its current packaging technology for CMOS devices. The problem is that the dimensions of the silicon have become too small for the bonding process they are using. "It's simply impossible," Ostmann says. "They have to do something new." The same company has power products where Chip-in-Polymer may offer new solutions to the problem of heat dissipation.

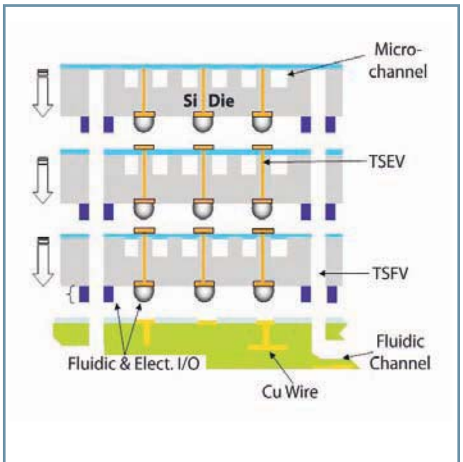


***Figure 2:** Diagram showing use of both electrical and fluidic through-silicon vias*

Joe Fjelstad, the promoter of the Occam Process, may have the shortest route to consumer products, based on the fact that his process uses off-the-shelf chip-scale packages. He has found an unusual degree of interest in Brazil, apparently because Brazil is a newcomer in the world of electronic manufacturing and has a very small installed base that represents investments in current assembly methods. "It is not easy to walk away from sunk investment," he explains, "which makes it all the more interesting to see the greatest interest coming from South America where there is no baggage to carry forward."

Fjelstad has been in discussions with Brazil's space agency and other research centers. There is interest in using the Occam Process to manufacture inexpensive, reliable cell phones and multi-band radios. There is also interest in Bluetooth appliances and, more specifically, in remote sensing devices for monitoring the health of rivers in the Amazon basin.

The approach being developed by Bakir at Georgia Tech – both electrical and fluidic vias connecting stacked chips – is probably the farthest from being used in consumer products, but is potentially the most promising. Most advanced microprocessors in use today are flip chips. They tend to run hot and are typically cooled by a metal heat sink carefully bonded to the back side of the silicon. A metal heat sink is a relatively inefficient passive method for extracting heat, but it works and is relatively inexpensive. However, it makes it impossible to stack two advanced microprocessors.

Bakir notes that through-silicon via technology, although not yet being used in manufacturing, is already well understood. "I think people know how to do it," he says. "I think TSV technology is fairly mature fabrication-wise. It's not ubiquitous in the consumer market or anywhere else now, but I think people have done a fair bit work on it to know its reliability characteristics."

Other developers of TSV technology tend to thin silicon chips from their initial thickness of around 600 microns down to somewhere between 30 and 80 microns. Bakir's team uses a different approach. They thin the silicon down to 250 to 300 microns and then etch their backside micro-channels down to within about 30 microns of the active, heat-producing front side circuitry.

They also do something else that has a profound effect on speed and performance. Since one die will be stacked on top of another and connected by electrical vias, they design the layout of each die in such a way that portions of the circuitry that frequently talk to each other are at opposite ends of the same electrical via. A signal doesn't have to travel halfway across a board through vias; it only needs to travel upwards or downwards about 300 microns. This dramatic shortening of interconnect distances, along with the ability to cool chips very effectively, is what gives their process such promise.

Although through-silicon vias are still a long way from consumer applications, there are some hints of what may be possible. Dr Azad Naeemi of Georgia Tech notes that many of the newer cell phones are battery-limited because they use so much power. "If 3-D brings you major savings in terms of power dissipation, eventually I think there will be a good maturation to use 3-D integration even for products like cell phones and other hand-held devices."

Bakir adds that through-silicon via technology makes sense in non-high-performance applications that use very small die. "When you have very small die," he explains, "that means you can squeeze more out of a wafer so you can sort of justify the cost of the TSV technology. You also need to offset the costs by having a lot of functional chips come out of that wafer that has the TSVs. Ultimately, application, performance gains and cost are key." ■

LETTER of the law

Myk Dormer

SHORT-RANGED, low-power wireless devices are usable throughout Europe – and much of the rest of the world – without the specific installation licensing that PMR systems relatives require, and without the certified operator training of marine and amateur radio services.

This is only permissible because every SRD has to conform to a specification very carefully written to minimise its potential to cause interference to other services. Limitations are placed on permitted frequencies of operation (the 'ISM bands'), on maximum RF output power and on the level of any off-channel spurii, or harmonics. Frequently, the modulation mode, occupied bandwidth and transmitter on-time are also restricted.

In Europe the governing spec for short-range low-power radio devices is EN300-220, currently in its v2.1.1 release. This specification is, in common with others of the type, not easy 'bedtime reading'. It needs to be very exacting in its definition of terms, methods and test procedures, but this in turn can make it difficult to extract the actual radio performance requirements from it. Refer to Note 1 for a synopsis (and Note 2 if you wish to download and read it in its entirety).

The specification concentrates on the transmitter (as, beyond its local oscillator leakage, a receiver is not a source of potential interference) and sets fairly practical performance targets. A transmitter complying with EN300-220 will not swamp the ISM band with wideband noise and overmodulation 'splatter', or put a spurious output on a broadcast channel, or an airband frequency.

But a problem can be seen when we consider the receiver parameters. For all but the safety critical (Class 1) receivers, the only requirement is that no emitted spurii exceeds 2nW. For ordinary "Class 3" receivers the rest of the performance parameters are undefined. It is entirely possible for an unscrupulous manufacturer to sell a "compliant to EN300-220 receiver" that has no chance of working in the real world.

NOTE 1: SYNOPSIS OF EN300-220 RADIO SPECIFICATIONS:

Operating temperature	-20 to +55 degrees	(general usage)
	-10 to +55	(mobile)
	+5 to +35	(indoor use only)
Frequency stability:	wideband (> 200kHz channels)	±100ppm
	25kHz channels, 300-500MHz	±2KHz

Refer to Table 6a on page 27 of EN300-220 for a complete listing (various channel spacings 6.25-200kHz, frequencies 25-1000MHz)

TRANSMITTER	spurii / harmonics	-36dBm	(up to 1GHz)
		-30dBm	(over 1GHz)
		-54dBm	(forbidden bands)
	"standby" spurious output	-57dBm	(up to 1GHz)
		-47dBm	(over 1GHz)

(forbidden bands are 47-74MHz, 87.5-118MHz, 174-230MHz, 470-862MHz)

	adjacent channel power	10uW	(< 20kHz channels)
		200nW	(≥ 25kHz channels)
RECEIVER	spurious emissions	-57dBm	(up to 1GHz)
		-47dBm	(above 1GHz)

(Measurements are made up to 4GHz for radios operating below 470MHz and up to 12.75GHz for radios operating above 470MHz).

This is just a very basic extraction of the primary radio spec limits. The transmitter tests also include transient spurious emission tests and the receiver testing can (for Class 1 and 2 radios) also include sensitivity and several spurious response and large-signal tests.

There are also various sub-clauses dealing with band or application-specific tests, dealing with limited duty cycles, listen-before-talk or spread spectrum operation.

Of course, no supplier will ever really attempt to sell a unit that actually won't receive anything at all, but there are a good number of module and chip manufacturers who do sell products where, although the sensitivity is good enough to pass on-the-bench tests, the spurious rejection (adjacent channel, image, blocking) and large signal performance can be so poor that the device fails to function when connected to a real aerial and is used on a congested band.

By specifying a Class 2 (or even Class 1) receiver performance the user can be a little more certain that the module has at least a usable level of sensitivity, and filter stopband performance good enough to match it, but unfortunately, the actual definitions of the receiver classes have been in something of a state of flux, and very few receivers being sold today are capable of meeting the current Class 1 requirements (see Note 3).

The conclusion here turns out to be a very common one: "Let the buyer beware!". Compliance to the 300-220 specification is mandatory, but is only the tip of the iceberg. Carefully inspect the manufacturer's datasheet and look for the parameters not covered by the basic spec compliance (most of the receiver measurements, in most cases).

There ought to be quoted specifications for sensitivity, image rejection, spurious responses, blocking and adjacent channel. (And, for example, if a narrowband radio has a spurious rejection or adjacent channel figure worse than 60dB, or a blocking spec under 80dB then "inadequate design" alarm bells should ring.) If a parameter is not quoted at all, then suspect a very poor spec.

Lastly, remember that there is no substitute for attaching the aerial to your radio and going out into the field and doing some tests. Good luck!

Myk Dormer is Senior RF Design Engineer at Radiometrix Ltd ***www.radiometrix.com***

NOTE 2: SPECIFICATION DOCUMENTS:

Overall short ranged device band allocation document:
http://www.erodocdb.dk/Docs/doc98/official/pdf/REC7003E.PDF
Current release of the main EN300-220 spec.
http://www.radiometrix.co.uk/test_report/radio/en_30022001v020101p.pdf

NOTE 3: CLASS 1 RECEIVER PERFORMANCE REQUIREMENTS

The EN300-220 provides for a more stringently tested sub-group of receivers, intended for safety critical applications. Receivers conforming to the Class 1 (and to a lesser extent, Class 2) groups must have adequately good spurious rejection and large signal handling specs.
Referring to the specification: *"4.1.1 Receiver classification. The receivers used in short range radio devices are divided into three classes of receivers, each having its own set of minimum performance criteria. This classification is based upon the impact on persons in case the equipment does not operate above the specified minimum performance level.*
Class 1 Safety critical SRD communication media; i.e. for devices serving systems where failure may result in a physical risk to a person.
Class 2 Function-critical SRD communication media; i.e. when a failure to operate correctly causes loss of function but does not constitute a safety hazard.
Class 3 Non-critical SRD communication media whose failure to operate correctly causes loss of function which can be overcome by parallel means."

Unfortunately, over time, the various versions of the EN300-220 spec have changed the actual requirements for Class 1 receivers, to the point that a receiver compliant to the spec in 2007 has little chance of complying in 2008, while appearing somewhat over designed when compared to the forthcoming 2009 requirements.
In fact, the current stringent Class 1 standard expects a low-cost SRD receiver to meet specifications as stringent as expensive PMR Class receivers complying with EN 300 086 or 300-113.
Comparing the performance requirements (the actual testing methods have changed between v1.3.1 and v2.1.1, making direct comparisons a little difficult. I have re-worded the measurements into commonly understood relative-to-carrier values):

EN 300 220-1 V1.3.1	(2000-09) was valid until 31 December 2007: 60dB Adjacent Channel Selectivity, 84dB Blocking.
EN 300 220-1 V2.1.1	(2006-04) current issue: 60dB Adjacent Channel Selectivity, 84dB Blocking, 65dB Intermodulation
EN 300 220-1 V2.2.1	(2008-04) Future standard, implemented 2009: 54dB Adjacent Channel Selectivity, 4dB Blocking (at ±2MHz only). No intermodulation measurement.

A 65dB intermodulation level is the same as that required by the exacting 300-086 and 300-113 land mobile radio specifications.
ETSI appears to be have realised the implications of demanding such a stringent high standard from a low-cost SRD receiver. Therefore, they are working on the new v2.2.1 standard for R&TTE Directive Article 3.2 requirement. This new Class 1 requirement is scheduled to be published on 27 January 2009.

http://webapp.etsi.org/workProgram/Report_WorkItem.asp?wki_id=27107
http://webapp.etsi.org/workProgram/Report_Schedule.asp?WKI_ID=27107

Christopher MacLeod and **Grant M Maxwell** from the Robert Gordon University in Aberdeen, Scotland, explain how evolutionary methods encountered in nature help build electronic circuits

Minds for Robots

IN THE 1950s and 60s, popular culture was entranced by robots. There was Robby in "Forbidden Planet", Gort in "The Day the Earth Stood Still" and many others. This fascination has continued to the present day, only the names have changed; now we have Commander Data of "StarTrek" and the NS-5 of "I Robot".

Yet, despite the interest and the obvious advantages of having intelligent machines to do dirty, boring or dangerous jobs, we are little nearer to creating a similar technology in the real world. This article outlines a new route towards such intelligence in machines – Incremental Evolution.

Approaches to AI

Historically there have been three approaches to creating intelligent machines. The first approach was to try and copy the biological brain. However, this contains billions of nerve cells (called neurons), interlinked by trillions of connections, and unravelling it is well beyond our current scientific capabilities.

The second approach, known as symbolic AI (artificial intelligence), was to build a large database of rules and instructions to allow the machine to make complex decisions. But we know that biological brains don't work like this. Simple rules also don't have the flexibility to work in real-world situations and, in any case, the database soon grows to unmanageable proportions.

Finally, there is the approach of modelling simple neural circuitry using "Artificial Neural Networks" – networks of simple processors, loosely based on real nerve cells. However, the resulting circuits are not complex or flexible enough to allow intelligence to emerge.

Artificial Evolution

The problems outlined above led researchers to consider the mechanism that allowed nature to develop the biological brain – evolution. Evolution works because the fittest individuals in a society tend to survive better and therefore have a higher chance of breeding and passing on their traits to the next generation. As such, over many generations the fitness of the whole population increases.

Engineers have designed artificial versions of evolution called Evolutionary Algorithms. We can illustrate how these work using an example. Suppose we want to design a filter as shown in **Figure 1**.

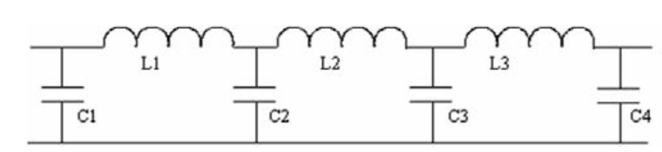


Figure 1: *A simple filter circuit*

The circuit can be represented by a string of numbers which are its component values. **Figure 2** shows a circuit with its components and the string which represents it.

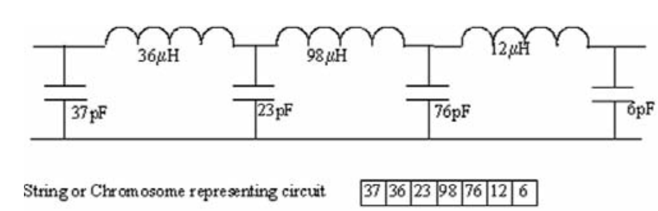


Figure 2: *A particular filter and its representative string*

We can generate lots of such strings (also sometimes called 'chromosomes') representing circuits like this – each chromosome is the component values of a single circuit. The starting point of an Evolutionary Algorithm is a number of such strings (called the 'population') filled with random numbers (random component values).

We then test each of these random strings to see how well it performs; in this case by comparing how good the circuit is with the perfect response. Having done this, we get rid of the worst strings; if we have a population of 99 strings say, we'd delete perhaps two thirds of them – the two thirds that are furthest from the ideal response. This would leave us with 33 strings. Next is to 'breed' them – just as in a population of animals, the fittest survive and breed together.

The breeding process is called 'crossover' or 'recombination'. It works like this: take two random strings and select a random point on them, then cross over all the numbers to the right of that point into the opposite string and vice versa, **Figure 3** shows the idea.

Before breeding:
12 54 34 65 03 87 67
37 36 23 98 76 12 06

After breeding:
12 54 34 98 76 12 06
37 36 23 65 03 87 67

Figure 3: *Crossover, also called 'recombination'*

Hopefully, in some of these events, the new string will inherit some good traits from the mother string and some different ones from the father, and will therefore be better than both.

Once this is done, the original population of 99 is recreated (the 66 new strings being the result of breeding). A small percentage of the numbers are then changed at random to add some variation into the population, an operation called 'mutation' and we start the whole process all over again: evaluation, culling, breeding and mutation. Over many generations of doing this, the population will improve to the point where some of the strings can solve the design problem satisfactorily. The technique is particularly useful in circuits which don't have good design rules or where compromises have to be made in the design.

Problems

The procedure outlined here has been shown to work well in many problems. It has been used to design analogue and digital circuits as well as DSP systems and artificial neural networks.

However, when we try and use it to design circuits to control intelligent machines, it has only limited success. The main reason for this is that the algorithm is inefficient when applied to large circuits. This is because of the many different combinations of components and wiring possible in such circuits; we say that the circuits have a large 'search space'. So what was successful for small problems is unworkable for large ones.

A related problem is that it is difficult to design the algorithm so that it can evolve a circuit which deals with many different kinds of input and output. For example, in a robot, there may be inputs from vision sensors, bump sensors and audio sensors. If you try and integrate these together, they sometimes conflict and interfere. This is why the human brain is not one big network, but lots of little ones (sometimes called modules), all doing their own thing but co-operating together.

How Nature Does It

Although current Evolutionary Algorithms model the selection of good traits within a population, this is only one feature of natural evolution. If we look at the evolution of organisms over time, the other important aspect is 'growth in complexity', where animals have changed from simple to complex forms over time, driven by competition.

When life started on Earth it was very simple – just single cells, in fact. From then until now, it has slowly but surely become more complex. Single-celled forms were replaced by simple multicellular animals, which eventually developed into jellyfish, then worms, complex invertebrates, fish, amphibians, reptiles and finally mammals – a march of progress from simple to complex. The extraordinary animals of today are only possible because they built on the successes of the past, adding more functionality to those which had gone before.

So, it is not just about blind growth, but about building upon a previously laid, firm foundation. The past triumphs of evolution are not discarded by nature, but new developments are built on top. This is particularly obvious in the brain, were it would have been impossible to rewire billions of neurons and trillions of connections each time it developed; the new changes had to build on top of the older ones. In fact, Richard Dawkins, in his famous book on evolution "The Blind Watchmaker" points out that incremental change is the only realistic way to evolve complex animals.

In other words, a traditional Evolutionary Algorithm simulates the selection of good traits in a population of (say) amoebas, but the amoebas can never evolve into jellyfish because the strings which represent the population members cannot become larger and more complex – and even if they did, the algorithm could not handle the extra complexity of the search-space generated.

Incremental Evolution

Incremental Evolution adds the idea of growth in complexity into Evolutionary Algorithms. We can illustrate how it works by considering the evolution of a circuit.

The algorithm works by initially making the circuit as simple as possible. An ordinary Evolutionary Algorithm is then used to evolve this simple system until it performs its task perfectly (or cannot get any better). This simple evolved circuit is then fixed and not allowed to change again.

Next, a 'module' of new components is added to the circuit; these are added to the pre-existing structure and are allowed to evolve. Again, when they can't get any better, the whole is permanently fixed and another new module is added. **Figure 4** shows this process operating on a filter.

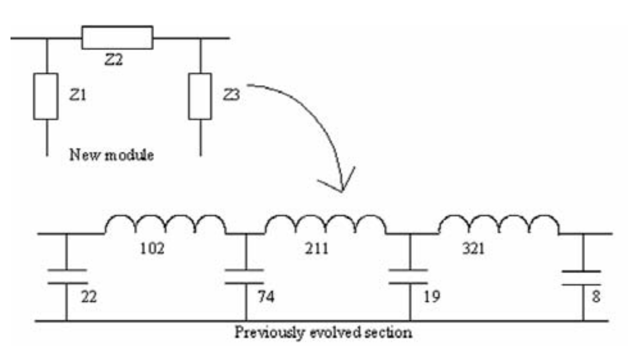


Figure 4: *A new module being added to a pre-evolved section*

A better understanding of this can be had by considering the evolution of a radio circuit. If we were to take dozens of transistors and other components and use a traditional Evolutionary Algorithm to design a radio receiver, it wouldn't get very far; the circuit is too complex and the search space too large.

However, if we only allowed one transistor and a few components, chances are that it would evolve a simple detector circuit, rather like a crystal set. Now, this doesn't work very well, but it does demodulate signals. If we now fixed this and allowed the algorithm to add a module, we have a good chance of evolving an RF amplifier in front of the detector. Fix all this and we might get an AF amplifier behind it. Try again and you might get a selection filter to tune it at the very front.

So, by allowing the system to grow like this, we can evolve much more complex systems than a simple Evolutionary Algorithm can – and systems which are automatically modular; for example, the filter in Figure 4 can evolve to give a much more complex multi-stage response than is likely to be produced by a single stage of evolution.

In fact, it turns out that in large systems with many connections, the search space of a traditional Evolutionary Algorithm grows frighteningly quickly, whereas in Incremental Evolution, the search space is simply that of the added module.

Robots

In our lab at the Robert Gordon University in Aberdeen, UK, Incremental Evolution was used to evolve a legged robot with vision sensors. The robot's sequence of evolution is shown in **Figure 5**.

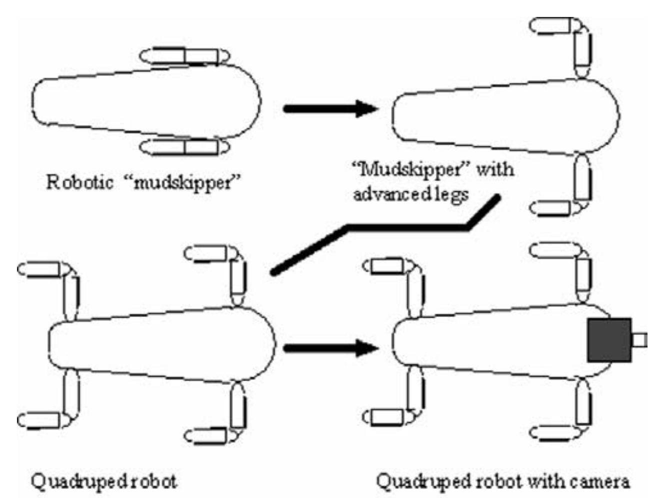


Figure 5: *An evolving legged robot*

An important principle can be seen in operation here. The robot's "body" and "mind" must evolve together; the principle of Incremental Evolution applies to the whole system, not just the circuit which controls it. This, again, keeps the search space in each iteration small; you might call it a holistic form of Artificial Evolution. After all, in nature, the brain of jellyfish goes with its particular simple body plan. In the terms of Evolutionary Algorithms, we say that the "fitness function" changes along with the current evolutionary stage.

The robot started of as simple as possible, in this case as a robotic "mudskipper". All it was able to do was pull itself along the floor with two simple inflexible legs. A neural network controller (a control circuit) was evolved to allow it do this. Next, the robot was given more complex legs, with two active degrees of freedom (a "hip" and a "knee"). Keeping the previously evolved network, another was evolved to control these new functions; the old network controlled the "hip" and the new, added one, the "knee".

Having done this, another two legs were then added, making the robot into a quadruped. Again, what was previously evolved was kept and further modules added on top of the old to control the new legs (although the algorithm was allowed to "cut and paste" previously evolved modules into new positions).

Having got our walking four legged robot, a vision system was evolved for it. This started off as just as one pixel and was allowed to evolve slowly, using the principles above, into a five by five pixel "robotic eye", which could recognise simple patterns as shown in **Figure 6**.

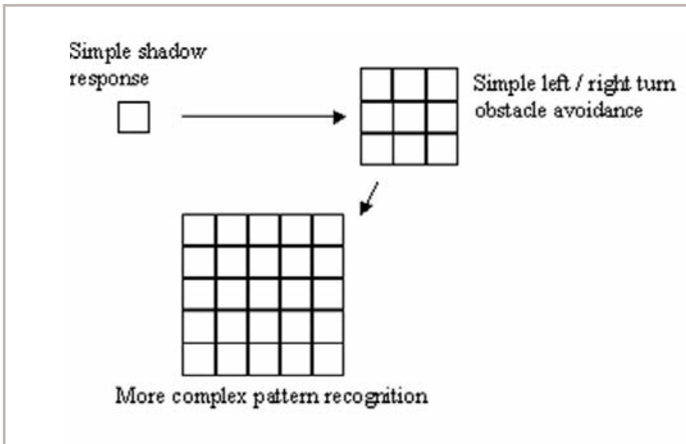


Figure 6: *The development of a robotic eye*

New networks were then added to interface those of the legs with the eye and produce a robot which could recognise patterns, turn and alter its gait accordingly. The final robot had over two hundred neurons in twenty two modules and could operate successfully in a variety of environments. **Figure 7** shows how one particular function evolved (in this case, the controller for a leg) as new modules were added.

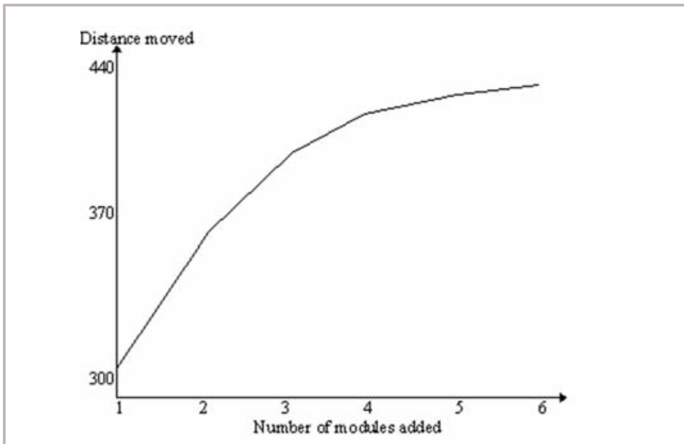


Figure 7: *A typical graph showing performance improvement as new modules are added*

The result of all this, is that, not only can a much more complex system be evolved, but that it is modular with parts of the network handling different functions. Hence, it has the ability to connect and integrate different sensor and actuator functions together. This modular network, however, is part of a fully functioning and co-operating whole.

Rules of Evolution

During the process of evolving the robot, it was discovered that there are some important "ground rules" for making the method work. If these are ignored then the evolution will stall and the system won't reach its full potential.

Firstly, the components in each module added must be as flexible as possible, in the case of electronics the algorithm should be allowed to choose these to be any component (resistor, capacitor, inductor, etc). In the case of a neural network, the flexibility of the neurons must be as high as we can make them.

Secondly, the algorithm evolving the system must be able to choose which connections are made as well as the component values and types. It was found that if this wasn't allowed to happen, the connections interfered with each other and stopped the system reaching its full potential.

Finally, usually there are a minimum number of components needed in each new module, if there are not enough then the system won't evolve correctly. This is similar to the first and second points, which indicate that the functionality of the added modules is critical and that each module must be as flexible as it can be.

It's also worth noting that even when the rules are followed it is possible for evolutionary "dead ends" to be reached, where further improvement is not possible. This also happens in the world of nature. In this case, modules must be removed and the system allowed to evolve again but in a different direction.

Applications

There are also many possible applications of Incremental Evolution in other areas of engineering. One of the most interesting is in biomedical engineering, in the development of prosthetic limbs. In this case, there is a direct incremental route from a simple system with all the joints of the limb fixed in place, to a complex system with all the joints free and controlled. As each joint is freed the controlling circuitry can be allowed to develop by adding to its structure, in the same way as in the robot.

Other examples include mechanical engineering; for example in aerospace engineering. Here too it is fairly obvious that sections of an aerodynamic design can be added incrementally.

There may even be lessons which biologists can learn about the early development of life and what works and doesn't in terms of evolutionary mechanisms.

Today we try and design complex systems inspired by biology, like intelligent robots, by analysing how humans and animals work and copying them. But when we see a human, we see four-and-a-half billion years of evolutionary progress. Each stage of that journey was built on the previous stage. Humankind did not come into being suddenly, without warning. It began its long trek as a single-celled organism in the primeval seas. We, our behaviour and our physical makeup, are a result of that development.

What, therefore, makes us think that we can build sophisticated intelligent systems like robots from scratch? Surely they too must build up their bodies and their behaviour in a similar way, just as we did, piece by piece, one step at a time. ■

FURTHER READING

www.rgu.ac.uk/eng/compint/page.cfm?pge=12909

- **S Muthuraman, C MacLeod and G Maxwell,** *"The development of Modular Evolutionary Artificial Neural Networks for Quadruped Locomotion"*, **IASTED ACS 03, p268-273.**
- **S Muthuraman, G Maxwell, C MacLeod,** *"The Evolution of Modular Artificial Neural Networks for Legged Robot Control"*, **Artificial Neural Networks and Neural - Information Processing, Springer (LNCS 2714), 2003, p488-495.**
- **Sethuraman Muthuraman,** *"The Evolution of Modular Artificial Neural Networks"*, **PhD Thesis, The Robert Gordon University, 2005**

Prof Dr Dogan Ibrahim from the Department of Computer Engineering at the Faculty of Engineering of Near East University in Nicosia, Cyprus, describes how a low-cost mobile robot can be used in robotics education

Robo-PICA: An Educational

ROBOTS ARE outstanding educational devices which are known to motivate students of all ages to learn maths and science, as well as computer programming, decision making and logical thinking. Robotics have been used in the classroom for many years and their use and acceptance as educational tools have been steadily expanding in the last few years as the cost of robotic systems dropped. Their programming has also been easier using high level languages, such as BASIC, PASCAL or C. Educational robots are found in two forms: either as flexible robot arms, or as mobile robots with wheels.

Educational robot arms consist of multiple joint arm assemblies where usually stepping motors are used to control the various arm movements. There are many educational robot arms in the market, designed for different levels of education. For example, Lynx 5 (**www.active-robots.com**) is a low-cost (less than £200) robot arm (see **Figure 1**), featuring base rotation, shoulder, elbow and wrist motion, and a functional gripper, designed for the advanced learner who also wants to learn to program microcontrollers.

More complex robot arms offer more degrees of freedom, where the robot arm is more flexible like a human arm. A program called RIOS (Robotic arm Interactive Operating System) is supplied with the Lynx robot arm, enabling students to develop powerful programs to control robot's motion for open-loop, as well as for closed-loop, control applications. For example, students can develop programs to move the robot arm to pick-up an object, and perhaps place it somewhere else.

Simple robot arms can be enhanced and made more intelligent by the addition of external sensors such as camera (for vision), microphone (for hearing), touch sensor (for feeling), light sensor (for movement and position) and so on.

The second group of educational robots is in the form of mobile devices. These are usually portable, battery-operated robots with wheels where a servo-motor or standard DC motors are used to control the robot's movements. Most such robots are used in navigation applications and they are equipped with a microcontroller card that provides the necessary interface signals to receive data from external sensors and to control the motors to move the robot to a desired location.

An example educational mobile robot is the Boe-Bot, manufactured by Parallax (**www.parallax.com**). This is a low-cost entry-level robot based on the Stamp series of microcontrollers, having two stepper motor driven front wheels and a passive rear wheel. Although the Boe-Bot can be used for many simple speed control and navigation projects, perhaps one of the biggest disadvantages of this robot is that the on-board microcontroller does not support the floating-point arithmetic directly and, thus, the movement of the robot, or the signals received from the sensors can not be very accurately defined. An external floating-point chip can be interfaced to the

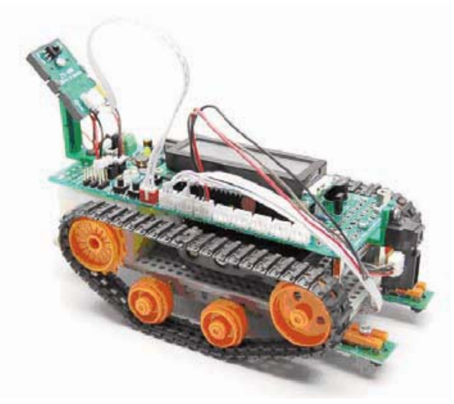


Figure 2: *Robo-PICA educational robot*

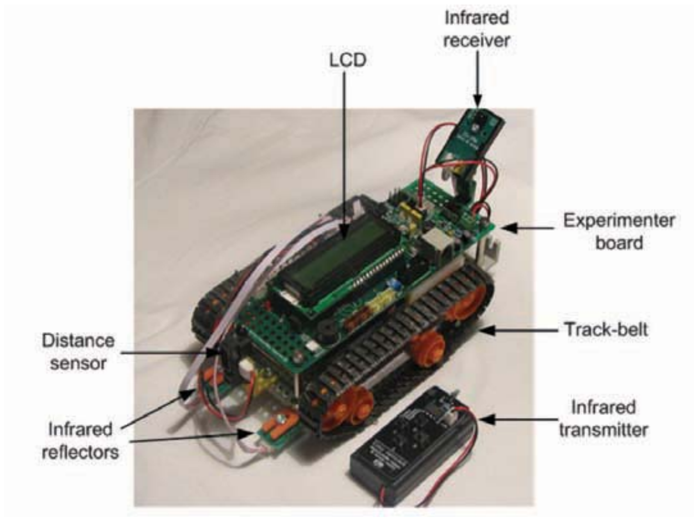


Figure 3: *Parts of the Robo-PICA robot*

Robot for Teaching

Figure 1: *Typical educational robot arm*

on-board microcontroller, but it is rather difficult to program this chip. It is, however, possible to remove the Stamp microcontroller card from the robot assembly and build an alternative controller card using a more sophisticated microcontroller such as the PIC18 series from Microchip. The robot can then easily be programmed using a high-level language such as BASIC, C or PASCAL, which usually support the floating-point operations fully.

Another example of an educational mobile robot is the Robo-PICA (see **Figure 2**), developed by INEX (Robotics Experiment With PIC Microcontroller, Innovative Experiment Company Ltd). This is a highly advanced, portable, battery-operated robot with a pair of geared DC motors, various sensors and an on-board PIC16F887 microcontroller card with ICD in-circuit programming feature. Details of this robot and its use in education are given with an example in the remaining sections of this article.

Robo-PICA's Features

Robo-PICA is an educational robot which is sold in disassembled kit form and this robot can be used as a development kit to learn the general PIC microcontroller programming and interfacing techniques. In addition, the theory and practice of robot movement and programming can easily be learned by developing programs to move the robot.

Robo-PICA is controlled by an on-board PIC16F887 type microcontroller and the robot system has the following features (see **Figure 3**):

- Mobile robot assembly with two geared DC motors
- Track-belt assembly set
- Experimenter board with:
  - PIC16F887 microcontroller
  - 20MHz ceramic resonator
  - LCD
  - DC motor drive circuits
  - Piezo buzzer
  - LED
  - ICD programming interface
  - USART interface
  - Servo motor interface
  - I2C bus interface
  - Switching power supply
- Remote control transmitter and receiver modules
- Distance measurement module
- Infrared reflector modules.

In addition to the basic robot assembly and the experimenter module, an ICD in-circuit programming module is supplied with the kit. This module is connected to the USB port of a PC and it is used to download program HEX code to the program memory of the on-board PIC16F887 microcontroller.

Robo-PICA can be programmed by either using the PIC assembly language, or using a high-level language, such as BASIC, PASCAL or C. The kit is supplied with a CDROM which contains a 2K program size limited DEMO version of the mikroC compiler. mikroC is a popular PIC microcontroller C compiler developed by mikroElektronika (**www.mikroe.com**). The DEMO version should be sufficient to carry out many robot experiments, but if required, the user can purchase the full unlimited version of the compiler at a low cost from the manufacturers or their distributors.

One of the very important features of Robo-PICA is the ICD in-circuit programming interface and the PICkit2 PIC microcontroller chip programming software supplied on the CDROM. Users can, for example, develop their programs using the mikroC language and then download the resulting HEX program code directly into the microcontroller program memory using the ICD in-circuit programming interface and the PICkit2 programmer software. This eliminates the need to have separate programmer device and programmer software.

A two-row character LCD is provided on-board which can be used for many purposes. For example, information such as robot movements can be displayed on the LCD second by second, or the LCD can be used for the calibration of the sensors.

An on-board LED and a piezo buzzer provide the programmer with visual and audio outputs that can be useful for either program debugging purposes or for indicating the status of various conditions linked to the movement of the robot.

An infrared transmitter-receiver module pair is provided with the robot with a physical range of up to 10 metres. The receiver module is mounted on the robot chassis in a visible high position. The transmitter module is basically a small handheld unit with four push-button switches mounted on top of it. Robot movements can be controlled remotely by developing programs to use the infrared transmitter-receiver pair module.

An infrared distance sensor module is provided with the Robo-PICA robot having a

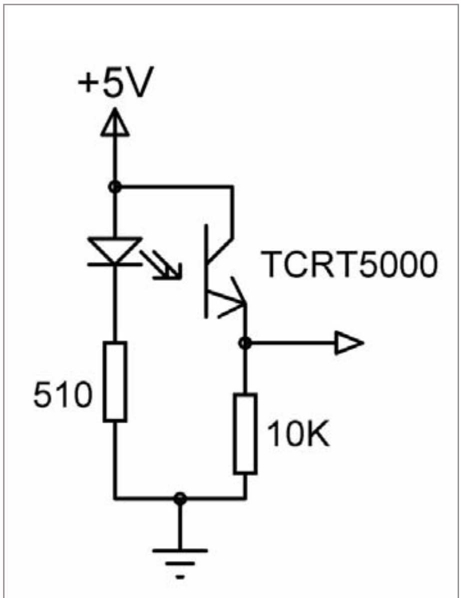


Figure 4: ZX-03 infrared reflector

```
BEGIN

    DO FOREVER
        Read both sensors
        Convert sensor readings to digital

        IF Left Sensor on White Surface AND Right Sensor  on White Surface
            Move Forward

        ELSE IF Right Sensor on White Surface
            Turn Left

        ELSE IF Left Sensor on White Surface
            Turn Right
        ELSE
            Turn Right
        END IF

    ENDDO
END
```

Figure 6: PDL of the robot control

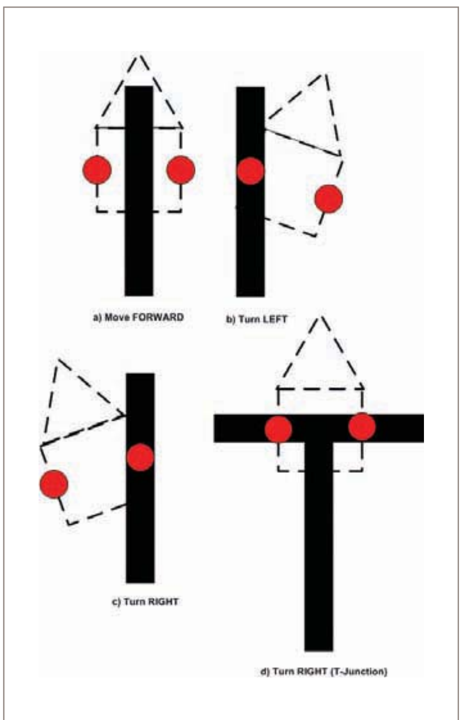


Figure 5: Possible robot movements

useful range of 4-30cm. This module is normally mounted directly in front of the robot and it can be used in collision detection and collision avoidance applications. For example, the robot can be programmed to detect obstacles in front of it and then avoid colliding with these obstacles possibly by moving back and changing its direction of movement. The distance sensor can also be used to create a map of the obstacles surrounding the robot.

Two infrared reflectors are mounted at the bottom and at both corners of the robot. With the aid of these reflectors the robot can be programmed and controlled to follow, for example, a dark line drawn on a white background. An example of programming the Robo-PICA for a line following application is given in a later section of this article.

A servo motor can be connected to the Robo-PICA instead of the supplied DC motor for more precise movement applications. The experimenter board provides the required signals for driving a servo motor. Thus, students are able to experiment with both DC motor and stepping motor based control and navigation applications.

Additional sensors such as compass, accelerometer, electromagnetic sensor, temperature sensor and GPS can easily be connected to the robot chassis. Connectors are provided on the experimenter board where analogue and digital I/O signals of the microcontroller are terminated, making it easy to connect external sensors to extend the sensing abilities of the robot.

The Robo-PICA robot is powered from four AA type batteries. A switching regulator is used to drive the +5V supply required by the microcontroller, the motors and the associated interface circuitry. A re-chargeable battery pack is recommended for educational and experimental applications where it may be required experiment with the robot for long durations. The batteries can easily be re-charged using the pair of battery terminals provided on the experimenter board.

The movement of the Robo-PICA robot is achieved using a pair of geared DC motors, coupled to wheels, plastic track-belt assembly, sprockets and axes. Using track-belt assembly enables the robot to move easily on almost any kind of surface.

Robo-PICA in Education

One of the problems with most microcontroller based system development process is programming of the target microcontroller's program memory. This is normally done using an external programmer hardware (and software) where the target microcontroller chip is inserted into the programmer socket and then the HEX program code is downloaded to the microcontroller's program memory. This process can be tedious as it may be required to remove the microcontroller from its socket many times during a development. Robo-PICA provides an in-circuit ICD interface which enables the on-board microcontroller to be programmed easily from a PC without being removed from its socket.

The Robo-PICA is supplied with a powerful high-level language compiler (mikroC) that simplifies the programming and debugging processes considerably. Any student with some knowledge of the C programming language can easily learn how to develop programs using the mikroC. The kit, in fact, provides all of the necessary hardware and

```
                    Robo-PICA LINE FOLLOWING
                    ========================

        This program shows how the Robo-PICA robot can be programmed to
        follow a black line drawn on a white surface. The robot is programmed
        to turn right at a T-junction.

        Right-hand sensor is connected to port pin RA0
        Left-hand sensor is connected to port pin RA1

        Author:  Dogan Ibrahim
        File   :  ROBOT.C
        Date   :  October, 2008

*******************************************************************************/
#include <motor.h>
#define threshold 300

int left_sensor, right_sensor;

//
// Read Sensor data and convert to digital
//
void Read_Sensor()
{
 right_sensor = ADC_Read(0);
 left_sensor   = ADC_Read(1);
}


void main()
{
 Delay_Ms(1000);                // Startup delay
 TRISA = 0xFF;                  // PORT A inputs
 ADCON1 = 0x80;                 // Define PORT A as analog

 while(1)
 {
  Read_Sensor();
  if((left_sensor > threshold) && (right_sensor > threshold))
     Forward(255);
  else if(right_sensor > threshold)
     S_Left(255);
  else if(left_sensor > threshold)
     S_Right(255);
  else
     S_Right(255);
```

Figure 7: *C code of the robot control*

software tools and parts for programming and testing robot based applications, and it is highly recommended by the author for educational robotic applications.

Some typical educational applications of Robo-PICA are:

- Learn the microcontroller system development cycle by developing general-purpose simple programs and download them to the on-board PIC16F887 microcontroller. For example, write programs to flash the LED, play music using the on-board buzzer, activate the motors and so on.
- Learn how to develop programs, functions, or sub-programs to move the robot forward, backward, rotate left and rotate right by the required amount.
- Develop programs so that the robot can detect obstacles using its distance measurement module and then move the robot to avoid such obstacles.
- Move the robot manually and remotely to any required location using the on-board infrared transmitter-receiver pair.
- Develop programs so that the robot follows a dark line drawn on a white background surface.
- Develop a map of the obstacles surrounding the robot by measuring the distance to all of the objects around the robot.
- Install additional sensors on the robot, such as a compass, GPS, an accelerometer, light-sensor, or a video camera so that more intelligent algorithms can be developed for complex robot movements.

Line-Following Robo-PICA

An educational example is given in this section to show how the Robo-PICA robot can easily be programmed to follow a dark (black) line drawn on a white surface. This example uses the ZX-03 infrared reflectors of the robot. As shown in Figure 3, these reflectors are mounted on the bottom right and left hand corners of the robot. As shown in **Figure 4**, ZX-03 consists of a TCRT5000 infrared diode and an infrared transistor. The infrared light emitted by the diode reflects off a surface and returns to the base of the transistor. The collector current of the transistor is proportional to the amount of reflected light and when used as an analogue sensor, the ZX-03 can detect shades of grey over short distances if the light in the room remains constant.

The suitable operating range of the ZX-03 is 3 to 8mm and the output voltage varies between 0.1 to 4.8V as the sensor is over different shades of grey. With a 10-bit PIC16F887 microcontroller A/D converter (1024 quantisation levels) and a +5V reference voltage, this corresponds to a converted digital value between 20 to 983.

A simple test shows that the converted value is between 400-900 when the reflector is on a white surface and the value when on a black surface is 0 to 150. A reference value of 300 is found by taking the average value of the minimum reading from a white surface and the maximum reading from a black surface. Thus, if the converted value is less than 300, the surface under the sensor is assumed to be black, otherwise, the surface is assumed to be white.

The width of the black line to be followed must be less than the distance between the two reflectors mounted at either corners of the robot. Depending on the shape of the line, the robot is required to make one of the following movements:

- Move forward
- Turn left

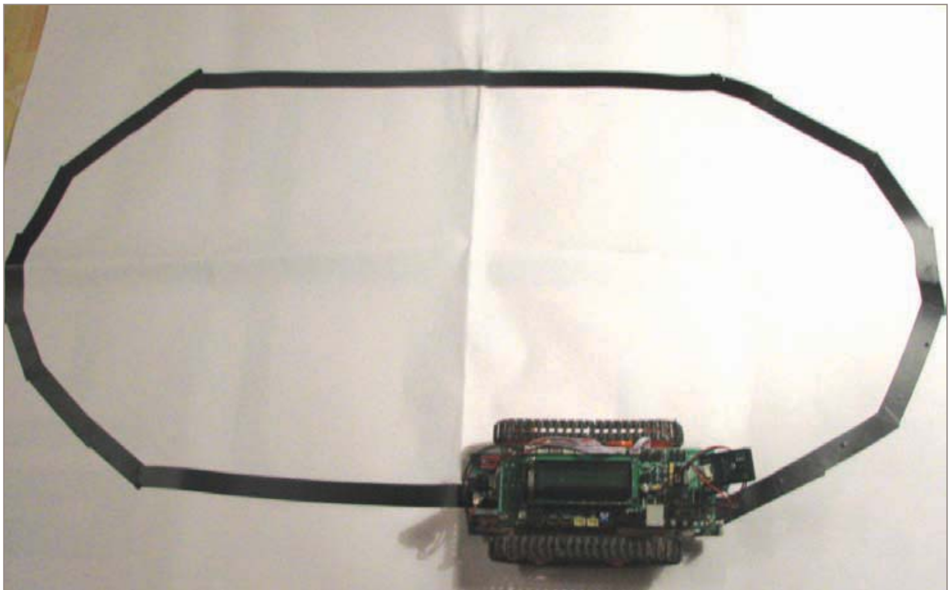


Figure 7: *C code of the robot control*

- Turn right
- Make a decision at a junction.

Move forward

As shown in **Figure 5a**, when both sensors are on the white surface (both sensor readings over 300), the robot should keep on moving forward to follow the black line.

Turn left

When the left sensor is on black surface (sensor reading less than 300) and right sensor is on white surface (sensor reading over 300) the robot is should be turned left to be back following the black line (see **Figure 5b**).

Turn right

As shown in **Figure 5c**, when the right sensor is on black surface (sensor reading less than 300) and left sensor is on white surface (sensor reading over 300) the robot should be turned right to be back following the black line.

At a junction

As shown in **Figure 5d**, if both sensors are on black surfaces (both sensor readings less than 300) then the robot is at a junction. With only two sensors we can not determine whether or not this is a T-junction or a 4-way junction (with a third sensor mounted in the front middle part of the robot further away from the robot chassis we can determine 4-way junctions). In this application we will be assuming that only T-junctions are allowed in the robot path. At a T-junction there is a choice and the robot can either move forward, or turn left, or right. In this application we will always turn right at a T-junction for simplicity (at a 4-way junction there is the choice of either turning left, or right, or moving straight on).

Figure 6 gives a summary of the robot control algorithm as a simple PDL description. If both sensors are on a white surface, the robot moves forward. If right sensor is on white surface and left sensor is on black surface, the robot turns left. If left sensor is on white surface and right sensor is on black surface the robot turns right. If both sensors are on black surface (e.g. at a T-junction) the robot turns right.

The actual mikroC code implementation is shown in **Figure 7**. The left and right analogue sensor voltages are stored in variables 'left_sensor' and 'right_sensor' respectively and are converted into digital in function 'Read_Sensor'.

The right-hand sensor is connected to port pin RA0 and left-hand sensor is connected to port pin RA1 and both port pins are configured as analogue inputs. The include file 'motor.h' is supplied with the Robo-PICA kit and this file contains a number of functions for moving the robot forward (Forward), backward (Backward), turning left (S_Left), turning right (S_Right), or for stopping the motors (Motors_Stop).

The speed of the robot's DC motors is controlled by the duty cycle of PWM signals. The arguments to the motor functions specify the duty cycles and they range from 0 to 255, with 255 giving 100% duty cycle (i.e. the highest speed). 'Threshold' is defined as 300 and, as discussed before; a sensor reading is above 300 when the surface under the sensor is white. The robot control algorithm is implemented in an endless 'while' loop.

A sample black line path, drawn on a white paper surface has been constructed using black electrical insulating tape. **Figure 8** shows a picture of the robot following this path. In this example the robot follows the path in a circular manner, i.e. there is no T-junction.

The Robo-PICA Kit's Applicability

This article has described how a low-cost mobile robot can be used in robotics education in technical colleges and universities. Robot Robo-PICA costs only £80 and is controlled with an on-board PIC16F887 type microcontroller that can be programmed on-board with an ICD in-circuit interface provided with the kit. In addition, the robot is equipped with an infrared remote-control receiver and transmitter pair, an infrared distance measuring module and a pair of infrared reflector modules.

Additional modules can be interfaced to the robot easily using the existing analogue and digital connectors and interface ports. For example, a hand-held GPS receiver (e.g. Garmin 60Csx, see **www.garmin.com**) can be mounted on the robot chassis together with a wireless device such as a Bluetooth, or long-range RF transmitter-receiver pair. Commands can then be sent to the robot remotely from a PC to move the robot to any required latitude and longitude position. In addition, complex algorithms can be developed and implemented on the microcontroller to detect and avoid any obstacles in front of the robot as the robot moves on its way to its destination.

Navigating and collision avoiding robots are commonly used in many military remote-control applications, as well as in commercial and industrial control applications.

Robo-PICA is a low-cost "all-in-one" robot, and should be an invaluable educational tool for teaching general microcontroller programming techniques and, in particular, mobile robotics theory and practice. Different line-following algorithms and different robot movement control techniques (e.g. PID control) can easily be experimented with this robot. The kit is highly recommended by the author. ■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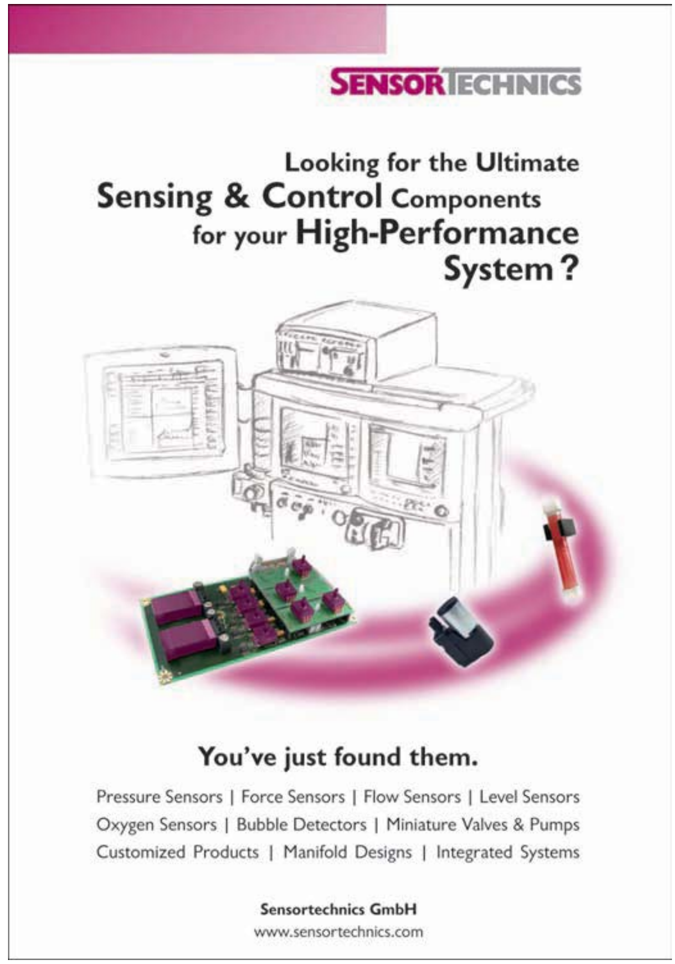
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Poor reliability and battery life are hampering wireless control technologies, explains **Steve Nguyen** from Echelon

Radio Frequency Control

A CONTROL network consists of sensors, actuators and other electrical devices that exchange information with each other over shared communication media. In order for information to be exchanged reliably, the communication media must be highly robust and able to compensate for sources of interference frequently found in the intended operating environment.

Users often employ two or more different media in control systems for cost and reliability reasons. For example, it may be prohibitively expensive to install new twisted pair wiring to reach existing devices, so a hybrid twisted pair and power line solution may be best for such an application.

Likewise, the presence of metal construction material or wireless data networks could make an all RF-based system unusable or unreliable; a hybrid RF and twisted pair system would overcome these limitations. Having access to a suite of media to create such hybrid solutions can mean the difference between a robust, reliable control network and one that has the stability and operational issues.

Everywhere and Nowhere

Through the use of mesh, or repeater-based networking and new protocols, RF technologies are purported to offer the performance of twisted pair solutions but with lower device and installation costs. Among the better known new RF-based technologies are: ZigBee, Z-Wave, Millennial Net and Dust.

Echelon recently completed a year-long investigation of these technologies. Our findings are very different from what we expected. We expected to test high performance technologies, highly reliable twisted pair replacement, but found just the opposite – the new RF technologies offered very poor robustness against sources of interference and very limited distance operation.

The underlying RF modems used within these control networks are made by a common pool of semiconductor manufacturers. While each RF technology supplier calls its solution unique, the technologies share many common underlying elements and limitations. For example, all of those systems use mesh networking, in which RF-based devices can also operate as repeaters, to compensate for the poor distance of their radio. Yet even with repeaters enabled, some systems in our tests could not operate reliably.

Signal Propagation Losses

The strength of an RF signal drops 6dB for every incremental doubling of open field distance with no impairments or obstacles. The presence of typical building construction materials further reduced RF signal strength. An RF signal drops inside a building with obstacles by about 25dB for every incremental doubling of distance. RF mesh network suppliers quote radio signalling distances assuming an open field transmission with no impairments or obstacles between the transmitter and receiver. This is wholly unrealistic.

In real-world environments such as a standard commercial building or home of roughly 2700 square feet, the situation proved quite difference. None on the radios could operate reliably at 30m. At distances as short of 10m the radios had insufficient operating margin to operate reliably over time. Turning on noise sources dropped the operating distance so low that repeaters would be required every 5 to 8m.

Network Traffic in Shared Frequencies

Since RF signalling is regulated by

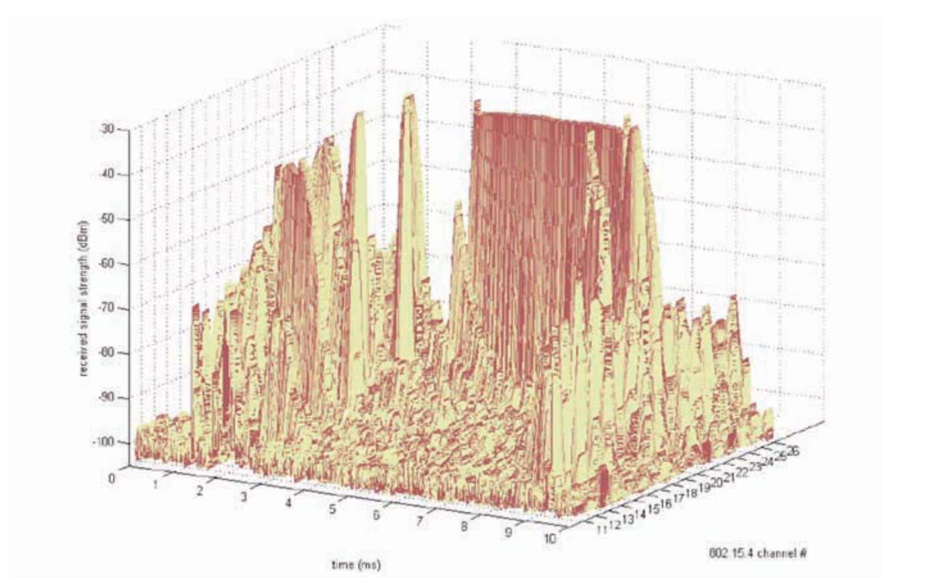


Figure 1: *WiFi router interference with ZigBee 802.15.4 radio*

Networking

governments al of the RF technology suppliers share their assigned RF frequency spectrum that's in common with other authorised RF-based devices and systems. The devices that share the 868MHz (EU), 915MHz (US) and ISM 2.5GHz bands that are unlicensed, mesh-based control networks operate on include 802.11 (WiFi) routers and network interfaces, cordless phones, Bluetooth devices, audio and video extenders, closed circuit television transmitters and other control networking devices.

The interference between difference wireless devices reduced reliable communication between any two devices. Various RF technologies use difference techniques to mitigate interference caused by other devices in their space. For example, WiFi and ZigBee use direct sequence spread spectrum (DSSS) to distribute the information over a wider bandwidth, while Bluetooth uses frequency hopping spread spectrum (FHSS) to randomly move from channel to channel. The net result, compounded by shared use of limited frequency range, is reduced system performance and reliability.

The growing number of RF devices operating within the shared frequency bands is creating virtual RF traffic jumps, and a corresponding degradation in reliability. In our tests, none of the existing mesh networking radios operated reliably in heavily trafficked RF bands – the radios experienced low effective bandwidth in most cases, and a complete loss of communication in extreme cases. **Figure 1** shows how a single WiFi router spreads energy across the frequency bands used by ZigBee to the point where reliable signal reception is not possible.

The proliferation of WiFi devices, cordless phones, Bluetooth-enabled devices and similar products in homes, buildings and factories make ZigBee-based devices extremely susceptible to interference. As with other impairments, WiFi devices might not be present when an RF mesh network is originally installed but could be added later.

FIELD-PROVEN TECHNOLOGY	None of the RF mesh technology suppliers have fielded millions of units. Indeed, none have even fielded the hundreds of thousands of units needed to statistically validate claims about reliable operation in a wide range of applications. The poor performance results observed in our testing may, in part, be attributed to the lack of understanding of real-world applications.
OPEN STANDARD	None of the protocols used by the RF mesh technologies has been adopted as an open standard. ZigBee claims to be an IEEE standard, but the protocol is proprietary and only the physical layer radio is an IEEE 802.15.4 standard. This means that ZigBee devices from different vendors may no interoperate.
FAULT TOLERANT	Mesh networking is claimed to offer fault tolerance as RF signals can be repeated by multiple devices throughout the mesh. However Z-Wave, Millennial Net and many other mesh networks depend on a controller within the network to coordinate the mesh repeaters. The dependence of these RF mesh networks on one controller makes them susceptible to a single point of failure and represents a major flaw in the system architecture.

Table 1: *Suitability of RF mesh technology*

RF Multipath and Distortion

Some manufacturers tout the use of DSSS and HSSS military spread spectrum as highly effective in preventing jamming, multipath and signal distortion. In fact, none of the mesh networking RF technologies have the sophistication and processing power of military radios. The result is erratic RF system operation despite the use of spread spectrum technology.

Multipath interference at 2.4GHz can often be overcome by moving a device a short distance (typically 3 to 6cm) to avoid the reflected wave. While this is a simple remedy for a mobile phone or cordless headset, it's less so for machines and control devices.

Once installed in the field, machines and other control devices face time-varying multipath effects caused by reflections from objects and people moving in and out of their operating range.

Multipath and signal distortion is difficult to troubleshoot since a technician must be present when a problem occurs in order to determine its source and a viable remedy. So what's the net result for product manufacturers? Higher warranty costs compared with a twisted pair of power line solution.

Battery Life

The use of battery-powered wireless technology adds another variable to the operation and maintenance equation. RF mesh technology suppliers have to balance battery life against system latency (delays from the time a signal is triggered until it can be acted upon). Dust networks allow repeaters to be battery-powered by powering down the device network and waking it up from time to time to conserve the battery life.

This technique works with respect to battery life but comes at a very high price – signal latency can exceed 15 seconds from the time a device is triggered until a reaction occurs. Such a long latency rules out the technology for any real-time applications, such as security monitoring, lighting, fault alarms, remote controls, or any activity requiring feedback to the user.

Even if batteries are not used with the RF control devices themselves – for example, because they're located in luminaries that already have access to mains power – battery-powered mesh repeaters may still be required. This is because the optimal location of a mesh repeater will be determined not by availability of the mains power but by the multipath interference, distortion effects and proximity to the devices whose signals must be repeated.

The approximate battery life of a control device can be easily calculated. For a simple device an alkaline battery would last approximately 11,500 hours, or 16 months. For large commercial building or homes with potentially hundreds of RF devices, the recurring cost of batters and their replacement would be exorbitant.

Considering the System Not Just the Radio

Control networks comprise many elements that are just as important as the communication medium. Together these elements determine how easy a system will be to update, maintain and support. RF mesh technology suppliers make claims about the suitability of their products for a wide range of control applications as shown in **Table 1**.

What Can Designers Do?

The current limitations of RF mesh technology should raise concerns among designers who are considering using it for their control systems. Adopting this immature technology poses high risks to company reputations, life cycle costs and warranty exposure.

Fortunately there are reliable, cost-competitive alternatives to RF mesh technology. Power line signalling offers a viable alternative for all residential and many building and industrial applications. Most of the control devices in these applications require a connection to electric power, be it AC or DC voltage, making power life signalling an ideal solution.

For new commercial building applications, free topology twisted pair wiring offers proven reliability, no battery replacement issues and low maintenance costs. For commercial building retrofit applications, such as overhead and emergency lighting devices, power line is a better and more reliable alternative to RF mesh networking.

Proven Technology

RF technology will improve over time; however we don't believe that manufacturers should be test vehicles for unproven technology. RF technology supplies should continue development until can produce a robust, field-proven solution on which product manufacturers can rest their brands.

The value of RF technology – if it can be made to work well at low cost – appears clear for a range of battery powered sensor monitoring applications. The value of mesh networking has yet to be proven in control applications.

Associate Professor **Dr Murat Uzam** from Nigde University in Turkey presents a series of articles on a project of how to develop a microcontroller-based PLC. This is the third article of the series focusing on the contacts and relay-based macros of the UZAM_PLC structure

PLC with PIC16F648A

IN THIS ARTICLE the following contact and relay-based macros are described: ld (load), ld_not (load_not), not, or, or_not, nor, and, and_not, nand, xor, xor_not, xnor, out, out_not, in_out, inv_out, set, reset. These macros are defined to operate on Boolean (one bit) variables.

All contact and relay-based macros are shown in **Table 1**, where the first column shows the macros, the second column provides the truth table of the respected macros, the third and forth columns show the ladder logic and schematic symbols of the macros respectively.

Let us now briefly explain these macros:

1. ld (load) – this macro has a Boolean input variable passed into it as "reg,bit" and a Boolean output variable passed out through "W". In ladder logic, this macro is represented by a normally open (NO) contact. When the input variable is 0 (respectively 1) the output (W) is forced to 0 (respectively to 1).
2. ld_not (load_not) – this macro has a Boolean input variable passed into it as "reg,bit" and a Boolean output variable passed out through "W". In ladder logic, this macro is represented by a normally closed (NC) contact. When the input variable is 0 (respectively 1) the output (W) is forced to 1 (respectively to 0).
3. not – this macro is used as a logical NOT gate. The input is taken from W and the output is send out by W.
4. or – this macro is used as a two-input-logical-OR gate. One input is taken from W and the other is taken from "reg,bit". The result is put into W.
5. or_not – this macro is also used as a two-input-logical-OR gate, but this time one of the inputs is inverted. One input is taken from W and the inverted input is taken from "reg,bit". The result is put into W.
6. nor – this macro is used as a two-input-logical-NOR-gate. One input is taken from W and the other input is taken from "reg,bit". The result is put into W.
7. and – this macro is used as a two-input-logical-AND gate. One input is taken from W and the other input is taken from "reg,bit". The result is put into W.
8. and_not – this macro is also used as a two-input-logical-AND gate, but this time one of the inputs is inverted. One input is taken from W and the inverted input is taken from "reg,bit". The result is put into W.
9. nand – this macro is used as a two-input-logical-NAND gate. One input is taken from W and the other input is taken from "reg,bit". The result is put into W.
10. xor – this macro is used as a two-input-logical-EXOR gate. One input is taken from W and the other input is taken from "reg,bit". The result is put into W.
11. xor_not – this macro is also used as a two-input-logical-EXOR gate, but this time one of the inputs is inverted. One input is taken from W and the inverted input is taken from "reg,bit". The result is put into W.
12. xnor – this macro is used as a two-input-logical-EXNOR gate. One input is taken from W and the other input is taken from "reg,bit". The result is put into W.
13. out – this macro has a Boolean input variable passed into it by W and a Boolean output variable passed out through "reg,bit". In ladder logic, this macro is represented by an output relay (internal or external relay). When the input variable is 0 (respectively 1) the output (W) is forced to 0 (respectively to 1).
14. out_not – this macro has a Boolean input variable passed into it by W and a Boolean output variable passed out through "reg,bit". In ladder logic, this macro is represented by an output relay (internal or external relay). When the input variable is 0 (respectively 1) the output (W) is forced to 1 (respectively to 0).
15. in_out – this macro has a Boolean input variable passed into it by "regi,biti" and a Boolean output variable passed out through "rego,bito". When the input variable "regi,biti" is 0 (respectively 1) the output variable "rego,bito" is forced to 0 (respectively to 1)
16. inv_out – this macro has a Boolean input variable passed into it by "regi,biti" and a Boolean output variable passed out through "rego,bito". When the input variable "regi,biti" is 0 (respectively 1) the output variable "rego,bito" is forced to 1 (respectively to 0).
17. set – this macro has a Boolean input variable passed into it by W and a Boolean output variable passed out through "reg,bit". When the input variable is 0, no action is taken, but when the input variable is 1, the output variable "reg,bit" is set to 1.
18. reset – this macro has a Boolean input variable passed into it by W and a Boolean output variable passed out through "reg,bit". When the input variable is 0, no action is taken, but when the input variable is 1, the output variable "reg,bit" is reset.

Examples

In this section, we will consider four examples, namely UZAM_plc_8i8o_exN.asm, N = 3, 4, 5, 6, to show the usage of contact and relay-based macros. These examples can be tested by downloading the files from **http://host.nigde.edu.tr/muzam/** and then opening the UZAM_plc_8i8o_exN.asm, N = 3, 4, 5, 6, program with MPLAB IDE and compiling it. After that by using the PIC programmer software, take the compiled file "UZAM_PLC_8i8o_exN.hex" and by your PIC programmer hardware send it to the program memory of PIC16F648A microcontroller within the UZAM_PLC. After loading the "UZAM_PLC_8i8o_exN.hex" switch the 4PDT in "RUN" and the power switch in "ON" position. Check each program's accuracy by cross-referencing it with Table 1.

Microcontroller **Part 3**

Macro	Truth Table

`ld macro reg,bit`
`movlw 0`
`btfsc reg,bit`
`movlw 1`
`endm`
	IN (reg,bit) → OUT (W)
	0 → 0
	1 → 1

`ld_not macro reg,bit`
`movlw 1`
`btfsc reg,bit`
`movlw 0`
`endm`
	IN (reg,bit) → OUT (W)
	0 → 1
	1 → 0

`not macro`
`xorlw 1`
`endm`
	IN (W) → OUT (W)
	0 → 1
	1 → 0

`or macro reg,bit`
`movwf Temp_1`
`movlw 0`
`btfsc reg,bit`
`movlw 1`
`iorwf Temp_1,w`
`endm`
	IN1 (W), IN2 (reg,bit) → OUT (W)
	0, 0 → 0
	0, 1 → 1
	1, 0 → 1
	1, 1 → 1

`or_not macro reg,bit`
`movwf Temp_1`
`movlw 1`
`btfsc reg,bit`
`movlw 0`
`iorwf Temp_1,w`
`endm`
	IN1 (W), IN2 (reg,bit) → OUT (W)
	0, 0 → 1
	0, 1 → 0
	1, 0 → 1
	1, 1 → 1

`nor macro reg,bit`
`movwf Temp_1`
`movlw 0`
`btfsc reg,bit`
`movlw 1`
`iorwf Temp_1,w`
`xorlw 1`
`endm`
	IN1 (W), IN2 (reg,bit) → OUT (W)
	0, 0 → 1
	0, 1 → 0
	1, 0 → 0
	1, 1 → 0

`and macro reg,bit`
`movwf Temp_1`
`movlw 0`
`btfsc reg,bit`
`movlw 1`
`andwf Temp_1,w`
`endm`
	IN1 (W), IN2 (reg,bit) → OUT (W)
	0, 0 → 0
	0, 1 → 0
	1, 0 → 0
	1, 1 → 1

`and_not macro reg,bit`
`movwf Temp_1`
`movlw 1`
`btfsc reg,bit`
`movlw 0`
`andwf Temp_1,w`
`endm`
	IN1 (W), IN2 (reg,bit) → OUT (W)
	0, 0 → 0
	0, 1 → 0
	1, 0 → 1
	1, 1 → 0

`nand macro reg,bit`
`movwf Temp_1`
`movlw 0`
`btfsc reg,bit`
`movlw 1`
`andwf Temp_1,w`
`xorlw 1`
`endm`
	IN1 (W), IN2 (reg,bit) → OUT (W)
	0, 0 → 1
	0, 1 → 1
	1, 0 → 1
	1, 1 → 0

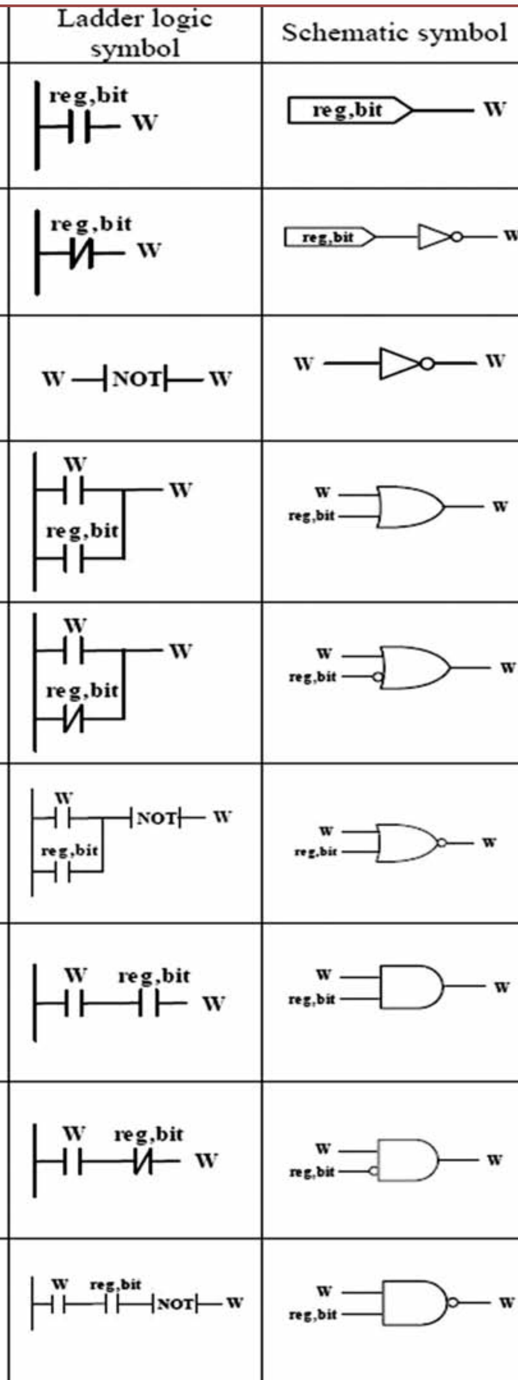


***Table 1:** Contact and relay-based macros*

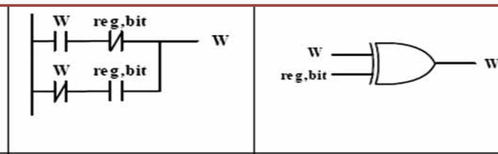
Continues on the next page

Let us now consider these four example programs. The first example program, "UZAM_plc_8i8o_ex3.asm", is shown in **Figure 1**. It shows the usage of the following contact and relay-based macros: ld, ld_not, not, out, out_not, in_out, inv_out. The schematic and ladder diagrams of the program are depicted in **Figures 2a** and **2b**.

The second example program, "UZAM_plc_8i8o_ex4.asm", is shown in **Figure 3**. It shows the usage of the following contact and relay-based macros: ld, out, or, or_not, nor. The schematic and ladder diagrams of this program are depicted in **Figures 4a** and **4b**.

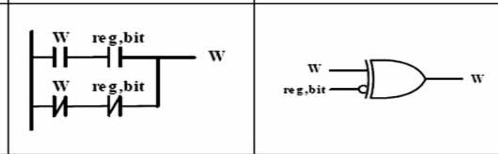
```
xor      macro    reg,bit
         movwf    Temp_1
         movlw    0
         btfsc    reg,bit
         movlw    1
         xorwf    Temp_1,w
         endm
```

IN1	IN2	OUT
W	reg,bit	W
0	0	0
0	1	1
1	0	1
1	1	0



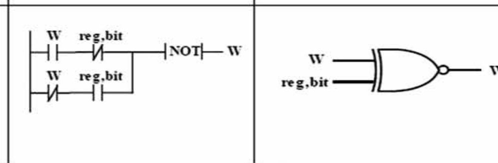
```
xor_not  macro    reg,bit
         movwf    Temp_1
         movlw    1
         btfsc    reg,bit
         movlw    0
         xorwf    Temp_1,w
         endm
```

IN1	IN2	OUT
W	reg,bit	W
0	0	1
0	1	0
1	0	0
1	1	1



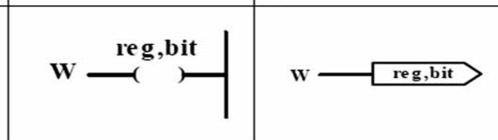
```
xnor     macro    reg,bit
         movwf    Temp_1
         movlw    0
         btfsc    reg,bit
         movlw    1
         xorwf    Temp_1,w
         xorlw    1
         endm
```

IN1	IN2	OUT
W	reg,bit	W
0	0	1
0	1	0
1	0	0
1	1	1



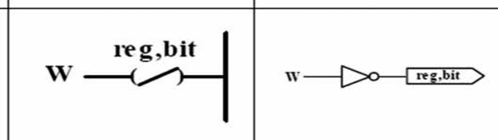
```
out      macro    reg,bit
         movwf    Temp_1
         btfsc    Temp_1,0
         bsf      reg,bit
         btfss    Temp_1,0
         bcf      reg,bit
         endm
```

IN	OUT
W	reg,bit
0	0
1	1



```
out_not  macro    reg,bit
         movwf    Temp_1
         btfss    Temp_1,0
         bsf      reg,bit
         btfsc    Temp_1,0
         bcf      reg,bit
         endm
```

IN	OUT
W	reg,bit
0	1
1	0

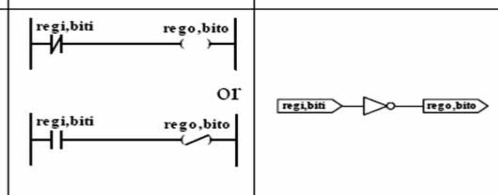


```
in_out  macro regi,biti,rego,bito
        local   L1,L2
        btfss   regi,biti
        goto    L2
        bsf     rego,bito
        goto    L1
L2      bcf     rego,bito
L1
        endm
```

IN	OUT
regi,biti	rego,bito
0	0
1	1

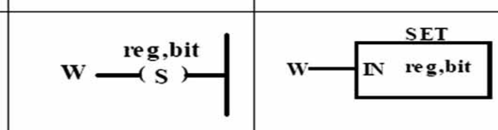
```
inv_out macro regi,biti,rego,bito
        local   L1,L2
        btfss   regi,biti
        goto    L2
        bcf     rego,bito
        goto    L1
L2      bsf     rego,bito
L1
        endm
```

IN	OUT
regi,biti	rego,bito
0	1
1	0



```
_set     macro    reg,bit
         andlw    1
         btfss    STATUS,Z
         bsf      reg,bit
         endm
```

IN	OUT
W	reg,bit
0	no change
1	Set



```
_reset   macro    reg,bit
         andlw    1
         btfss    STATUS,Z
         bcf      reg,bit
         endm
```

IN	OUT
W	reg,bit
0	no change
1	Reset

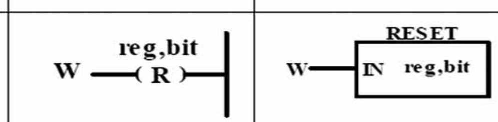


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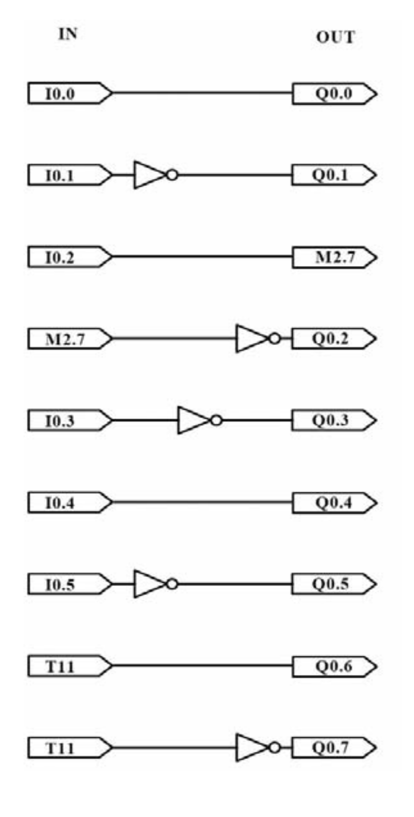
Table 1: *Contact and relay-based macros*

```
.
     #include <cntct_mcr_def.inc>;Contact & Relay based macros
.
;--------------- user program starts here ------------------------
     ld           I0.0         ;rung 1
     out          Q0.0

     ld_not       I0.1         ;rung 2
     out          Q0.1

     ld           I0.2         ;rung 3
     out          M2.7

     ld           M2.7         ;rung 4
     out_not      Q0.2

     ld           I0.3         ;rung 5
     not
     out          Q0.3

     in_out       I0.4,Q0.4    ;rung 6

     inv_out      I0.5,Q0.5    ;rung 7

     in_out       T11,Q0.6     ;rung 8

     inv_out      T11,Q0.7     ;rung 9
;--------------- user program ends here ---
```

Figure 1: *The user program of UZAM_plc_8i8o_ex3.asm*

The third example program, "UZAM_plc_8i8o_ex5.asm", is shown in **Figure 5**. It shows the usage of the following contact and relay-based macros: ld, out, and, and_not, nand. Its schematic and ladder diagrams are depicted in **Figures 6a** and **6b**.

The forth example program, "UZAM_plc_8i8o_ex6.asm", is shown in **Figure 7**. It shows the usage of the following contact and relay-based macros: ld, out, xor, xor_not, xnor, _set, _reset. The schematic and ladder diagrams are depicted in **Figures 8a** and **8b**.



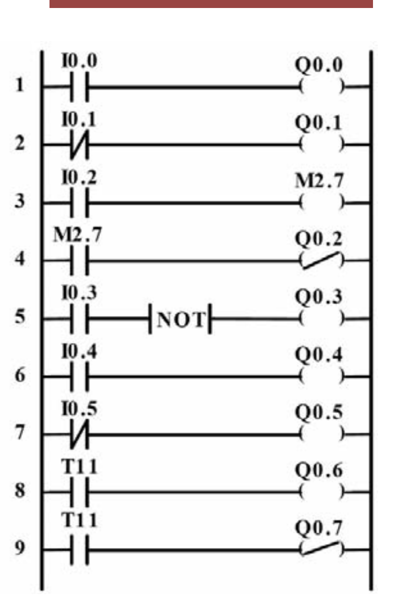
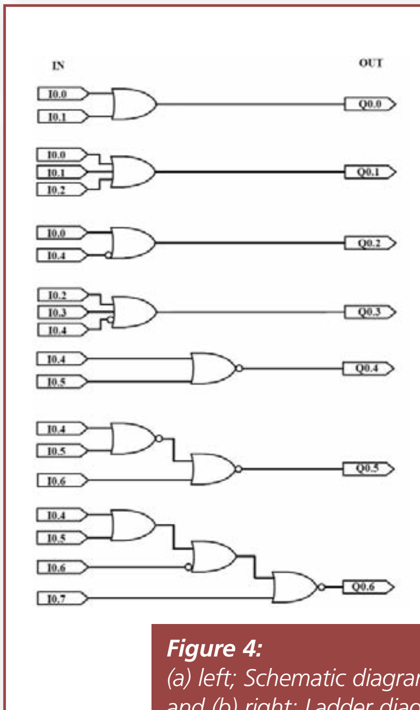


Figure 2:
(a) above; Schematic diagram
(b) below; Ladder diagram
for the user program of
UZAM_plc_8i8o_ex3.asm

```
.
     #include <cntct_mcr_def.inc>;Contact & Relay based macros
.
;--------------- user program starts here ------------------------
     ld          I0.0        ;rung 1
     or          I0.1
     out         Q0.0

     ld          I0.0        ;rung 2
     or          I0.1
     or          I0.2
     out         Q0.1

     ld          I0.0        ;rung 3
     or_not      I0.4
     out         Q0.2

     ld          I0.2        ;rung 4
     or          I0.3
     or_not      I0.4
     out         Q0.3

     ld          I0.4        ;rung 5
     nor         I0.5
     out         Q0.4

     ld          I0.4        ;rung 6
     nor         I0.5
     nor         I0.6
     out         Q0.5

     ld          I0.4        ;rung 7
     or          I0.5
     or_not      I0.6
     nor         I0.7
     out         Q0.6
;--------------- user program ends here -------------------------
```

Figure 3:
The user program of
UZAM_plc_8i8o_ex4.asm



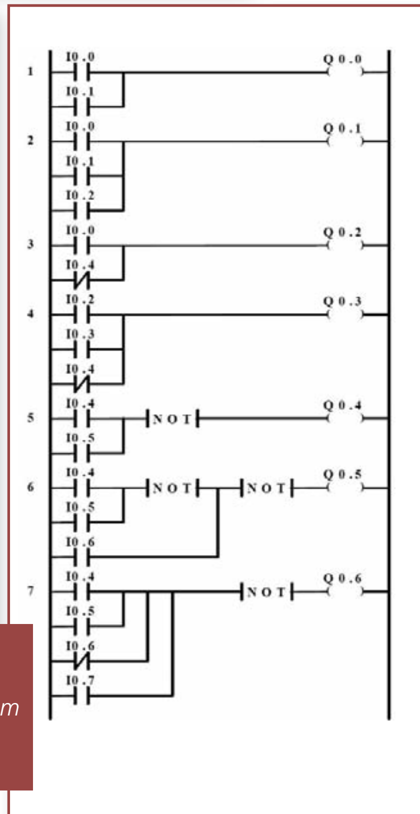


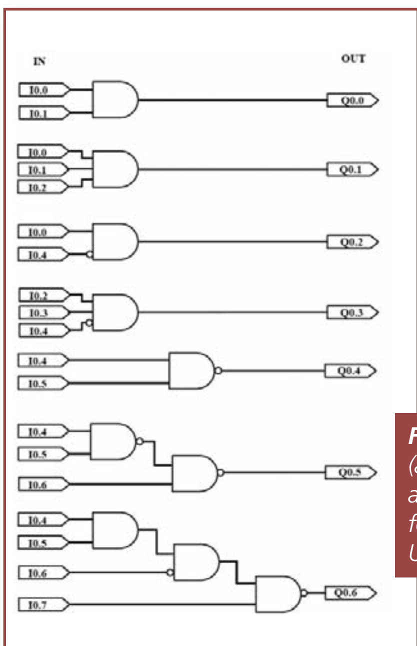
Figure 4:
(a) left; Schematic diagram
and (b) right; Ladder diagram
for the user program of
UZAM_plc_8i8o_ex4.asm

```
#include <cntct_mcr_def.inc>;Contact & Relay based macros

--------------- user program starts here -----------------------
	ld		I0.0		;rung 1
	and		I0.1
	out		Q0.0

	ld		I0.0		;rung 2
	and		I0.1
	and		I0.2
	out		Q0.1

	ld		I0.0		;rung 3
	and_not		I0.4
	out		Q0.2

	ld		I0.2		;rung 4
	and		I0.3
	and_not		I0.4
	out		Q0.3

	ld		I0.4		;rung 5
	nand		I0.5
	out		Q0.4

	ld		I0.4		;rung 6
	nand		I0.5
	nand		I0.6
	out		Q0.5

	ld		I0.4		;rung 7
	and		I0.5
	and_not		I0.6
	nand		I0.7
	out		Q0.6
--------------- user program ends here -------------------------
```

Figure 5: *The user program of UZAM_plc_8i8o_ex5.asm*

```
#include <cntct_mcr_def.inc>;Contact & Relay based macros

--------------- user program starts here -----------------------
	ld		I0.0		;rung 1
	xor		I0.1
	out		Q0.0

	ld		I0.2		;rung 2
	xor_not		I0.3
	out		Q0.2

	ld		I0.4		;rung 3
	xnor		I0.5
	out		Q0.4

	ld		I0.6		;rung 4
	_set		Q0.7

	ld		I0.7		;rung 5
	_reset		Q0.7
--------------- user program ends here -------------------------
```

Figure 7: *The user program of UZAM_plc_8i8o_ex6.asm*



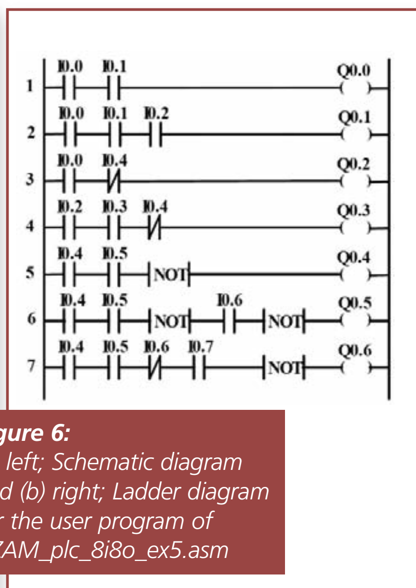
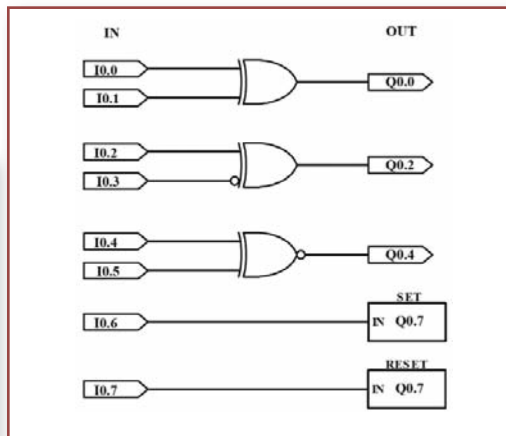


Figure 6:
(a) left; Schematic diagram and (b) right; Ladder diagram for the user program of UZAM_plc_8i8o_ex5.asm



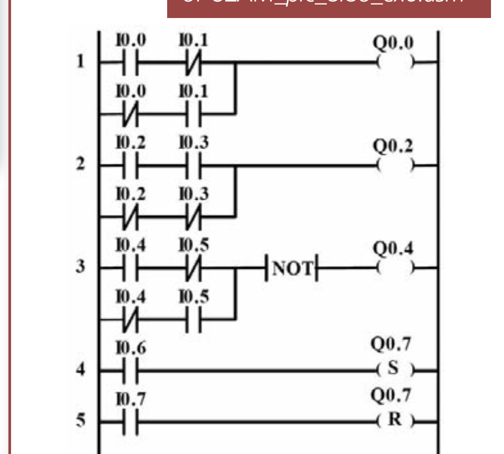


Figure 8:
(a) above; Schematic diagram and (b) below; Ladder diagram for the user program of UZAM_plc_8i8o_ex6.asm

PREDICTING DISPLAY READABILITY BY USING THE JND METRIC

By Robbie Sharpe, UKDL

IN PROFESSIONAL, industrial and military applications, flat panel displays (FPDs) are being more frequently used in adverse ambient environments. How to accurately quantify the readability and/or usability of such devices is an area that has received much interest in recent years.

Until now, it has been impossible to give a display a unique "identifier" that recommends that the display would be guaranteed as usable for certain tasks in particular environments. The display's contrast ratio (CR) is commonly used at present, but this parameter is only of use for verification purposes and it cannot be used to predict or model how a display will perform in different applications.

Figure 1: *Pilot and co-pilot workstation*

Available Methods

A measurement and prediction method has been adopted for displays in military aircraft cockpits. This is called the "Perceptible Just Noticeable Difference" (PJND) method, developed by BAE Systems. However, it is only applicable for the tasks in the highly specified environment of aircraft cockpits. An example of such an environment is shown in **Figure 1**.

We have adapted this PJND method such that a display can be given a numerical usability score. The method is the Just Noticeable Difference (JND) technique using a vision model devised and extensively developed by Barten. One JND equates to the smallest perceptible change in luminance that the eye can detect; Barten has modelled this across the range 0.0500cd/m^2 to just under 4000cd/m^2. **Table 1** shows some of the levels of luminance that are appropriate for various JND values.

From the data in this table we can discern that:

1. 0.0500cd/m^2 is just perceptibly different to total black
2. 0.0547cd/m^2 is just perceptibly brighter than 0.0500cd/m^2
3. 119.1326cd/m^2 is 500 JND steps from perfect black
4. There are 1024 (10-bit) JND steps from black to a white of 3993.4040cd/m^2
5. At low luminances the JND step is about 10% of the luminance
6. At mid luminances the JND step is about 1%
7. At high luminances the JND step is about 0.5%.

The non-linear nature of the perception of grey level is illustrated in **Figure 2**.

It should be noted that this non-linear perceptual behaviour is the crux of this method. If, for instance, a particular task were to require 20 JNDs at a low ambient light level then, if this same task were to be carried out at a higher ambient light level, it will still require 20 JNDs. This is so since the JND steps allow for the change in contrast sensitivity of the eye with luminance. What this means, in essence, is that we can carry out any usability trials at 'normal' levels of luminance, confident in the knowledge that the results obtained can be applied to much higher levels of luminance encountered in high ambient environments.

JND	LUMINANCE CD/M^2
1	0.0500
2	0.0547
3	0.0594
:::	:::
500	119.1326
501	120.0109
502	120.8950
:::	:::
1021	3941.8580
1023	3967.5470
1024	3993.4040

Table 1*: JND and relevant luminance level*

Modelling the Environment

In order to successfully implement the model we have to model the environment and have knowledge of typical tasks that users will perform with displays.

Taking the environment first, three worst-case environmental scenarios are considered, where the display panel had to be read in an ambient situation that had three options: Sun Forward, Sun Rear and a High Ambient condition. These situations could occur in any FPD application – driving a car, flying a plane, using an outdoor ATM, for example.

Sun Forward

The display is positioned such that the user also has the sun in their forward field of view.

Sun Rear
The sun is directly behind the user bathing the display in sunlight.

High Ambient
The sun is obscured by cloud for instance, but there is still a very high illuminance falling onto the display surface.

In order to calculate the level of illuminance that can fall onto the display surface, information about the display's physical location is required, i.e. is it mounted on a North or South facing wall, recessed into a surround, installed within a vehicle etc. The magnitude of sunlight available that can illuminate the display surface depends on:

- Geographic location
- Time of day (solar altitude)
- Season
- Regional climate
- Local weather
- Cloud conditions

It is important to take all of these factors into account when predicting daylight illumination. In all viewing scenarios there is some light from glare that can enter our eyes, such as sun in your forward field of view, for instance. From the technical literature (BAE Systems for instance have done extensive research in this area), it is possible to obtain typical values for certain scenarios and applications; these have to be included in the modeling process.

The levels of luminance and illuminance that can normally be expected are shown in **Table 2**; it should be noted that these values estimated for the generic worst case. These can be changed if required to suit any specific environment, for example inside a car if the actual ambient conditions are known.

SCENARIO	DIFFUSE LUX	SPECULAR LUX	GLARE CD/M^2
Sun Rear	100,000	20,000	75
Sun Forward	10,000	70,000	350
High Ambient	20,000	20,000	75

***Table 2**: Proposed levels of luminance and illuminance*

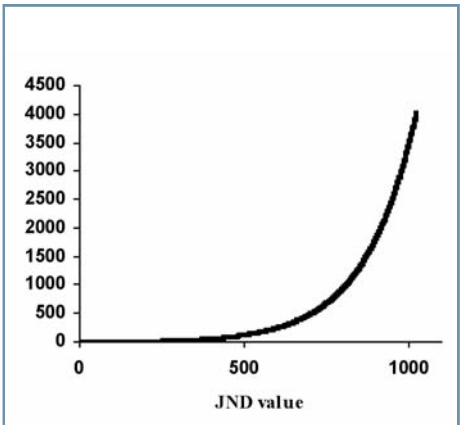


***Figure 2:** Non-linear perception of grey level*

Since we wish to model what an observer sees when looking at a particular display screen, we need to know the spectra from all contributions that are likely to enter the observer's eyes. To do this we require the display output spectrum (both white screen and black screen); we also need to be able to predict how much light will be reflected from the display surface back to the observer (specularly and diffusely). This requires four (six for some instances) simple measurements that are fairly straightforward to carry out.

Finally, we need to know how much light is likely to enter the observer's eyes from glare contributions (i.e. sun forward scenario).

The modelling process (refer to **Figure 3**), gathers together all the foreground and background spectra from all contributions; from these the levels of luminance (foreground and background) that enter the eye are quantified and can be calculated.

When we interact with a display we may be attempting to perform many differing tasks. We need to be able to classify and quantify as many tasks as possible that are performed, whilst at the same time keeping these to a manageable set of generic tasks. We have identified three main tasks that are common to most display applications.

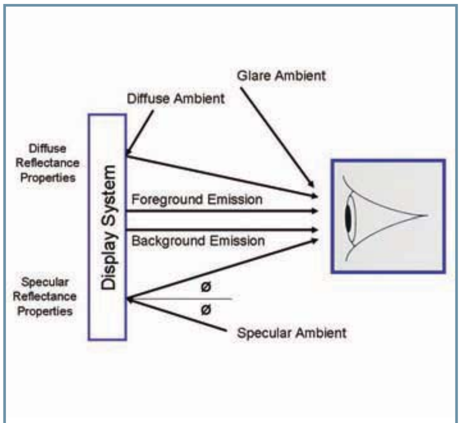


***Figure 3:** Modelling all spectra that can enter the eyes*

Simple Static: Identify and use a display system showing simple static text, for instance read the text on an information display at an airport.

Complex Static: Find, identify and use information on a display showing complex but static information, for instance complex graphics on web pages.

Complex Dynamic: Find, identify and use information on a display showing complex and dynamic information, for instance moving digital maps, video advertising and thermal images.

Calibrating the Scale

In order to 'calibrate' our usability/ readability scale, we had to determine the JND requirements for a particular task. In an ideal world we would have shown individuals real images taken from an application, for instance a simple static information page from an ATM. In reality, this method is prone to subjective response and is difficult to classify and quantify what it is about the image that makes it easy or difficult to interact with.

Instead, we showed participants what we deemed to be equivalent screen scenarios and equated these to a JND value appropriate to that task.

We showed participants a Landolt 'C', a well-known and extensively used visual stimulus. For the simple static case a single 'C' was presented to subjects in the middle of the screen (see **Figure 4**).

The contrast was varied as was the orientation of the gap, the task for the subjects was to determine the orientation of the gap. This allowed us to determine an ideal contrast and from this we equated the JNDs required for that particular task. Remember, we can work out the JND value from the total foreground and background luminance; it is then simply foreground JND value minus background JND value.

This is then the minimum JND required for that particular task in that environmental

Figure 4: *Landolt 'C' on screen*

scenario; this is, therefore, the baseline of usability. We additionally did this for the single 'C' anywhere on screen, to determine if a further search time penalty is added.

For the complex static case, we showed multiple Cs on screen (this is equivalent to viewing a complex scene which is static, for instance find the second junction on a SatNav system screen). Again, the task of the subjects was to detect the one 'C' which has its gap orientated different to all others, as previously the contrast was varied, and as before an ideal contrast and hence JND value can be computed.

It is interesting to note that the time taken by the subjects to detect the 'C' with the different orientation can be used to predict JND values that rely on a time constraint. For example "glance times" for in-vehicle information screens; more JNDs would be required to get the same information in a quicker time.

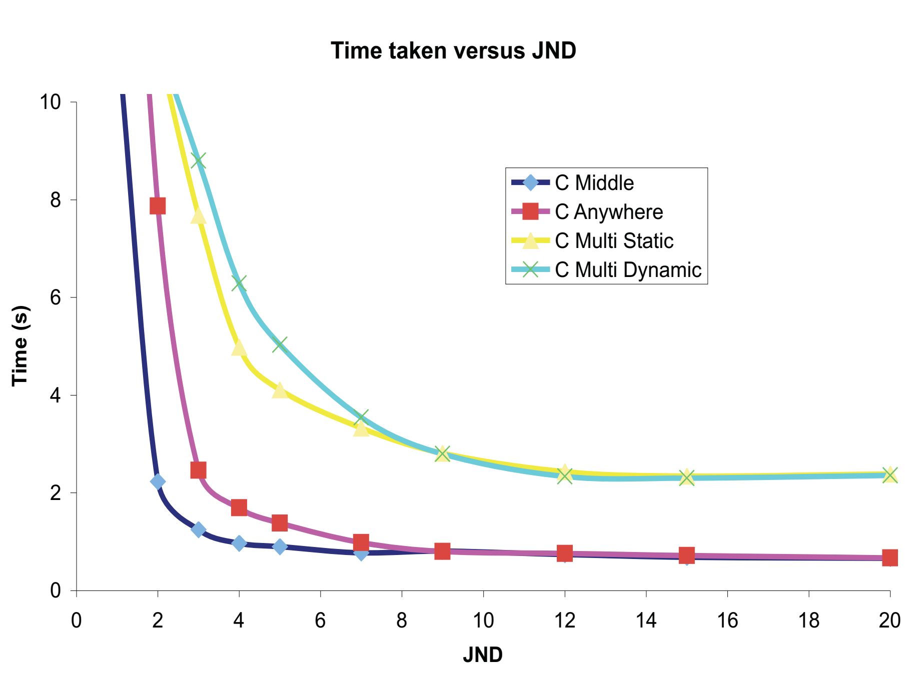


Figure 5: *Chart showing time taken versus JND required for task*

Figure 6: *Display that is not so easy to read*

Complex Dynamic Case

For the complex dynamic case we once again showed multiple Cs but this time they were moving about at random on the screen; this is equivalent to getting information from a screen that has moving imagery, for instance video advertising. As previously, the task of the subject was to detect the 'C' that had different orientation, from this as before we computed the JNDs required. The following chart shows the minimum JNDs required to perform the tasks outlined.

Only a few JNDs are required to perform the pertinent tasks, so at this point we should stop and consider the implications. On many occasions a display is rendered unusable due to reflections (both specular and diffuse) from various surfaces in front of the display itself.

If the display system (including all surfaces placed forward of the display itself) had been measured, it would have been possible to predict if the display system was capable of achieving these minimum values. If it had the display would have been at least just usable. Obviously more JNDs mean that the display is not only usable but also looks good (or better at least).

Figure 6 shows the effects of both diffuse and specular reflections, this has resulted in the degradation of the image as shown.

A spreadsheet has been formulated that allows the input of display parameters (white and black screen spectra also reflectance properties). It is also very simple to vary the environmental ambient luminance/illuminance levels to suit any particular scenarios.

Using this method it is possible to say how many JNDs a particular display is required to produce to enable a specific task in a certain environment to be performed. It is possible to predict how changes to the display will alter the usability of the display system, for instance the inclusion of a filter on the front of the display. The exploitation of this metric will allow the displays community to better specify their requirements to vendors.

Robbie Sharp is Knowledge Transferer at the UK Display & Lighting Knowledge Transfer Network (UKDL). ■

HOW TO GET RID OF THE SPARE BITS IN A SHIFT REGISTER

WHAT DO YOU do with the spare bits of a shift register? For example, if you want to build an 18-bit shift register, you might consider using five 4-bit shift registers (such as LS74194s) end-to-end, but that will give you 20 bits. Can the chips be wired up to give the appearance of only holding exactly 18 bits?

I met this problem many years ago, when I was a programmer working on Elliott 920B and 920M computers for the RAF's Nimrod and Jaguar aircraft. These successful computers had an 18-bit word length (long before the microprocessor revolution reduced us to 8 or 16 bits). The 920B used diode and transistor logic, and the main registers of the machine were bit-sliced across 18 separate cards.

When the time came to upgrade the processor to use TTL chips, it had to be kept compatible with the earlier machines. The programmers expected to be able to clear bits out of either end of the 18-bit registers by using shift instructions, and using five 4-bit chips, this data might have unexpectedly reappeared from the spare bits.

One proposed solution was to microcode the TTL implementation, in such a way that shift instructions shifted further than the programmer specified and then shifted back. For example, if the central 18 bits of the 20 were used to represent the 920's register (with one spare bit on either side), then an N place shift in either direction could be microcoded as an N+1 place in that direction, followed by a one place shift the other way. But this would have wasted two clock ticks on every shift instruction.

I never did find out what the engineers actually did then, and now Elliott 920s probably only exist in museums (see http://www.ourcomputerheritage.org). But a little lateral thinking shows that there is a better solution to this problem, which could still be of wider interest. The trick is to avoid spare bits at either end of the register by overlapping and duplicating some of the other bits.

Figure 1 shows how two 4-bit LS74194 universal shift registers are normally wired to provide an 8-bit shift register, which can be cleared, or shifted left or right one place, or "broadside" loaded. Only the data connections are shown; the power, clock and operation select lines are omitted for clarity.

Figure 2 shows how the same two chips can be wired as a 6-bit register, with two of the inputs and two of the outputs duplicated. Note especially how the shift inputs between the chips are not connected to the nearest bit of the other chip, rather they are connected two bits further across.

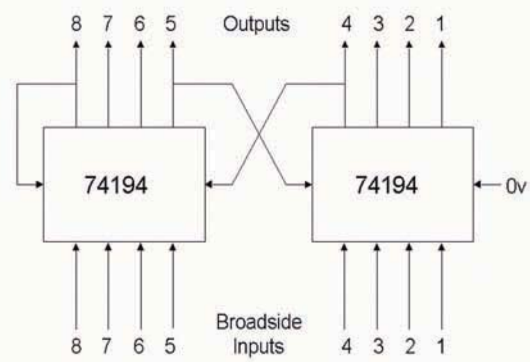


Figure 1:* *8-bit shift register

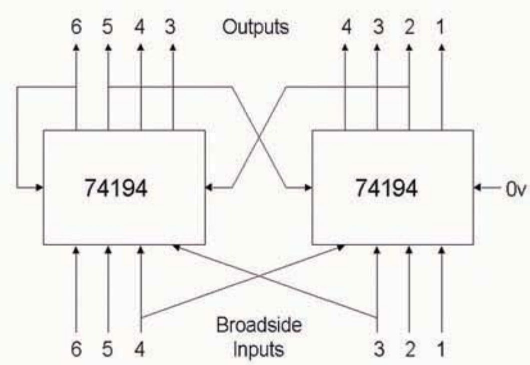


Figure 2:* *6-bit shift register

In both figures, the most significant (leftmost) shift input is shown as connected to the most significant output bit, so that right shifts regenerate the sign bit of a signed number, whereas a left shift shifts zeros in. For unsigned numbers, connect this bit to ground, to shift zeros in both ways.

Terry Froggatt
UK

TIP 1: A SOLUTION FOR WIDE INPUT BUCK/BOOST CONVERTER APPLICATIONS

By Henry Zhang and Wilson Zhou, Linear Technology

A common problem faced by a power supply is how to generate an output that at any time can be above or below the input, particularly in battery-powered systems. Many conventional solutions, such as two-stage power converters, SEPIC converters or Flyback converters, suffer from bulky component requirements and low efficiency. The LTC3780 synchronous 4-switch buck/boost controller avoids these pitfalls by using a novel high efficiency, single inductor topology. When compared with a traditional SEPIC or flyback converter, an LTC3780-based solution improves efficiency, up to 8% at full load, and significantly reduces supply size.

This controller has a 200kHz-400kHz constant frequency current-mode architecture, which allows seamless transitions between boost, buck/boost and buck operating modes. Unlike traditional boost converters, the LTC3780 buck/boost converter has fast and accurate cycle-by-cycle current limit in the short circuit condition and provides true soft-start during power-up.

Figure 1 shows a simplified LTC3780 4-switch buck-boost converter. When V_{IN} is lower than V_{OUT}, switch A is always on and synchronous switch B is always off, and the boost side switch C and synchronous switch D turn on and off alternately, behaving as a typical synchronous boost converter.

When the V_{IN} is higher than V_{OUT}, the LTC3780 operates in buck mode, with switch A and B turning on and off alternately, while switch C is always off and

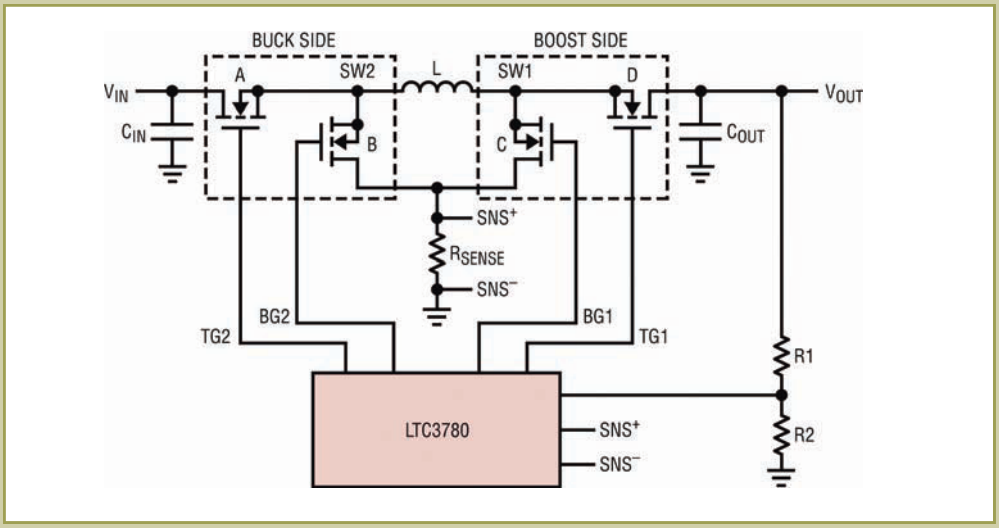


***Figure 1:** Four-switch LTC3780 synchronous buck-boost converter*

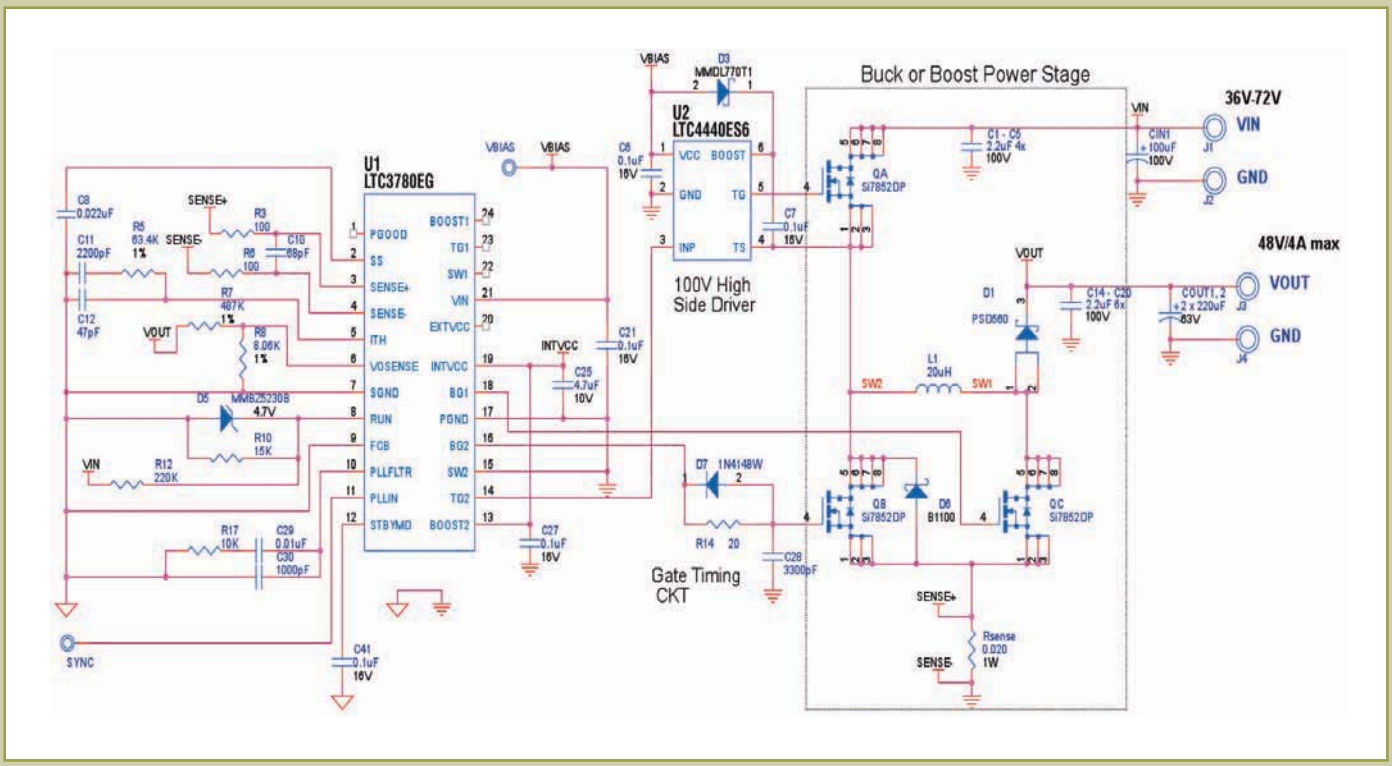


***Figure 2:** 36-72Vin, 48V/4A output buck-boost converter schematic*

switch D is always on. When V_{IN} is close to V_{OUT}, the LTC3780 converter operates in buck-boost mode with all the switches alternating.

High Input/Output Voltage LTC3780 Buck-Boost Converter

The LTC3780 has four sets of integrated FET drivers for a wide 4V-30V (36V max) input and output voltage range. However, some applications such as 48V telecom systems and automotive systems require even higher input or output voltage. To extend the input and output voltage range, a high voltage high side FET driver should be used.

Figure 2 shows the schematic of a design with 36V-72V telecom input voltage and tightly regulated 48V output with maximum 4A load or approximately 200W output power. In this design, because of the high input voltage, the 100V-rated LTC4440 high-side driver is used to drive the buck side top FET Q_A. Internally, the LTC3780 has about 50ns dead time between the top gate and bottom gate signals to avoid the bridge FET short-through.

Because the LTC4440 gate driver has a typical 30ns propagation delay, as shown in **Figure 3**, the dead time between the top FET Q_A turn-off and bottom FET Q_B turn-on is reduced from 50ns to a marginal 20ns with the LTC4440. To compensate for the additional Q_A turn-off delay caused by the LTC4440, a simple R/C/D turn-on delay timing circuit is added to the gate of Q_B. When the bottom gate signal BG2 goes up, R_{14} and C_{20} in Figure 2 add additional delay. When the bottom gate signal turns off, the diode D_7 can still discharge the gate of Q_B quickly.

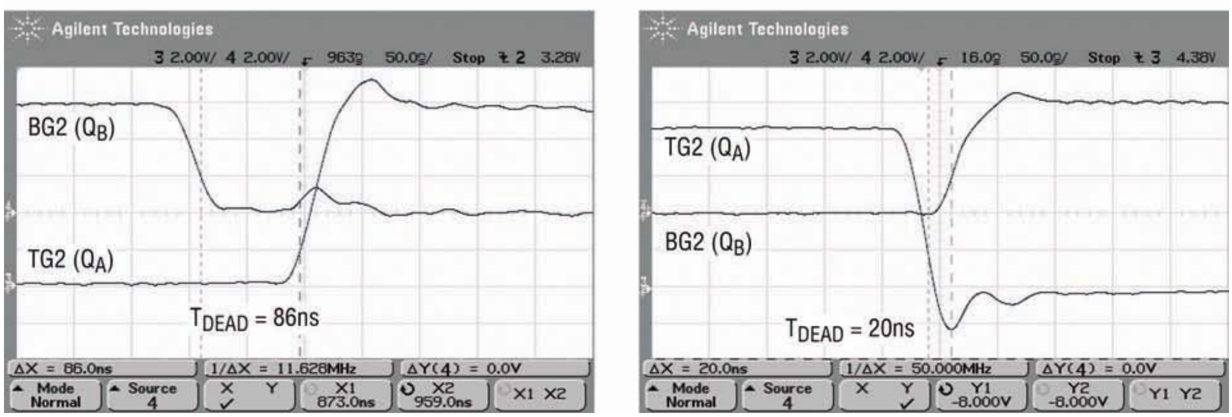


Figure 3: *Buck side FET gate timing with the external LTC4440 FET driver*

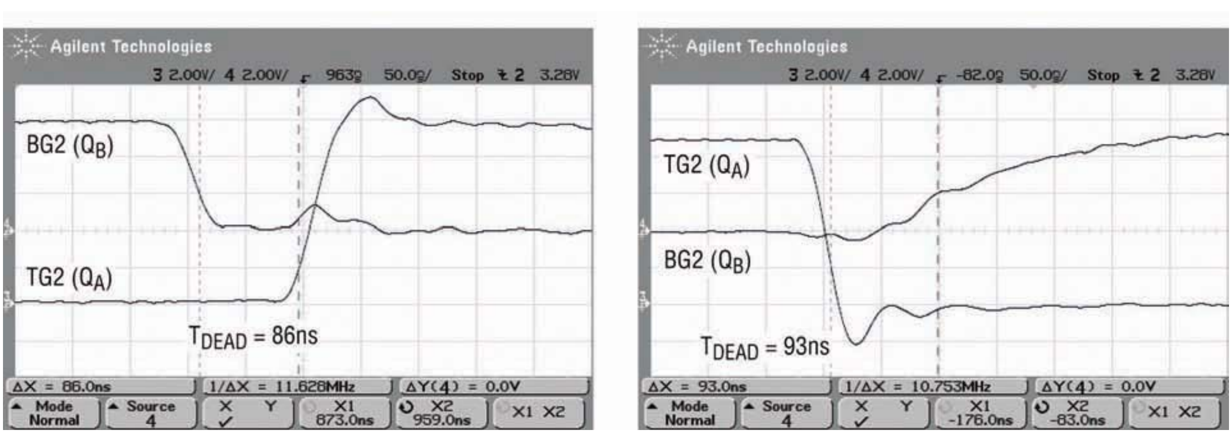


Figure 4: *Improved buck side FET gate timing with LTC4440 driver and additional R/C/D turn-on delay circuit on Q_B gate*

As shown in **Figure 4**, with the R/C/D delay timing circuit, the dead time between Q_A turn-off and Q_B turn-on is increased from 20ns to 93ns. It is necessary to point out that the bottom synchronous FET Q_B is always operated in the zero-voltage-switching mode; therefore, the R/C/D delay circuit does not increase the switching loss of Q_B significantly.

On the output boost side, the synchronous boost switch D can be replaced with 60V-rated Schottky diode D_1. As a result, neither an external high-side driver nor delay time circuit is needed. Because of the output voltage is 48V, the impact on the converter efficiency by using Schottky boost diode is less than 1%.

Unfortunately, if the switch D is needed with LTC4440 for better efficiency, the R/C/D delay circuit is not desirable for boost switch Q_C because the increased switching loss. In this case, Ref [3] offers another solution to compensate for the dead time on the boost side with the LTC4440.

Efficiency and Thermal Test Results

The measured efficiency of this 48V buck-boost converter is shown in **Figure 5**. With three Si7852 SO-8 PowerPAK MOSFETs, one 5A/60V Schottky diode PSD560, a 14mm x 14mm inductor, the converter has higher than 90% efficiency over a wide 10-100% load range and 36V-72V input range. At $48V_{IN}$, 200W output, the efficiency is as high as 97.2%.

Figure 6 shows the measured thermal pictures of the power MOSFET Q_A, Q_B, Q_C and boost side Schottky diode D_1. The pictures are taken at 36V, 48V and 72V input with 48V/200W output. The ambient temperature is 25°C. Without any heat sink or forced air flow, the maximum FET/diode case temperature rise is just 47.6°C at $48V_{IN}$ and 54.5°C at $72V_{IN}$ worst case condition. Because of its high efficiency and fast over-current protection, the LTC3780 supply has low thermal stresses and is very reliable.

Conclusions

The LTC3780 offers an efficient and high performance solution for wide input buck/boost converter applications for telecom, automotive and industry systems. By adding a high-side FET driver LTC4440, the input voltage can be easily extended. If the output voltage is high, the synchronous boost FET can be replaced with a Schottky or high-speed switching diode to simplify the design.

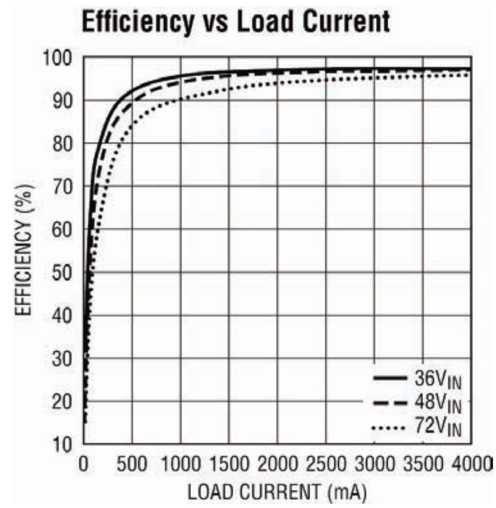


Figure 5: *Tested efficiency vs load at different input voltage (fs = 250kHz, Vo = 48V)*

References:

[1] "*LTC3780 High Efficiency, Synchronous, 4-Switch Buck-Boost Converter Data Sheet*". **www.linear.com**

[2] Theo Philips, Wilson Zhou, "*Breakthrough Buck-Boost Controller Provides up to 10A from a Wide 4V-36V Input Range*" Linear Technology Magazine, Volume XV, No.3, Sept 2005

[3] Kurk Mathews, "Using the LTC4440 Driver to Extend the Voltage Range of LTC3780 Supplies", Linear Technology Design Article, 2005.

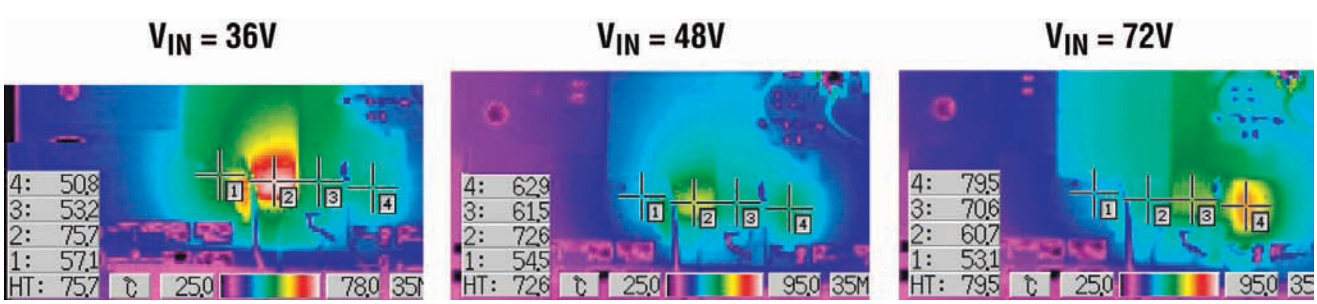


Figure 5: *Measured power MOSFET / diode temperature without heat sink, no air at 48Vo/4A output (Markers: 1 – D_1, 2 – Q_C, 3 – Q_B, 4 – Q_A)*

TIP 2: SWITCHED MODE POWER SUPPLY FOR COLD CRANK CONDITIONS

By Sanmukh Patel, Systems Engineer, Mixed Signal Automotive, Texas Instruments

In power supply selection for 5V microcontrollers, the appropriate topology must be selected to ensure uninterrupted functionality during cold crank condition of a vehicle (see **Figure 1**). In using a linear regulator to provide a voltage source to the microcontroller, a reset can be invoked during the crank pulse when the battery voltage falls below 4V (Vmin).

Another issue with using linear regulators is the inefficiency during normal operation; the overall regulator efficiency could be lower than 30%. In addition to the power loss factor with the linear regulator, the application requires good thermal management implementation to prevent thermal shut-down during high operating ambient temperature and maximum output loading.

The most efficient topology to address these issues is a buck/boost switch mode power converter, which maintains a fixed output voltage during the voltage excursion of a vehicle battery (range 4V to 40V). The TPIC74100Q1 from Texas Instruments (see **Figure 2**) has integrated power switches, which operate in a synchronous configuration for the highest converter efficiency.

The transition between buck to boost mode during low-input voltages occurs at approximately 5.4V as the input voltage slews to 4V. As the battery input voltage recovers after the cold crank pulse, the converter reverts back to the buck mode of operation.

Introducing switch mode topologies does have its own challenges when applied in an automotive environment. By paying particular attention to the design and printed circuit board (PCB) layout and component selection, these issues can be minimised. This helps address interference due to the switching noise of the power supply in the amplitude modulation frequency range (AM band). Implementing frequency spread spectrum and slew rate control can help lower radiated emissions related to switched mode power supplies.

This switch mode topology introduces electromagnetic compatibility concerns with other electronic circuits powered from the same network and/or components in the near vicinity, which have conduction lines crossing this aggressor circuit.

A monolithic solution implements several techniques to limit the electromagnetic interference (EMI) due to the switching action.

Slew rate control and corner shaping helps reduce fast current changes during the switching edges, which contributes to the EMI. This could increase the switching losses and power dissipation.

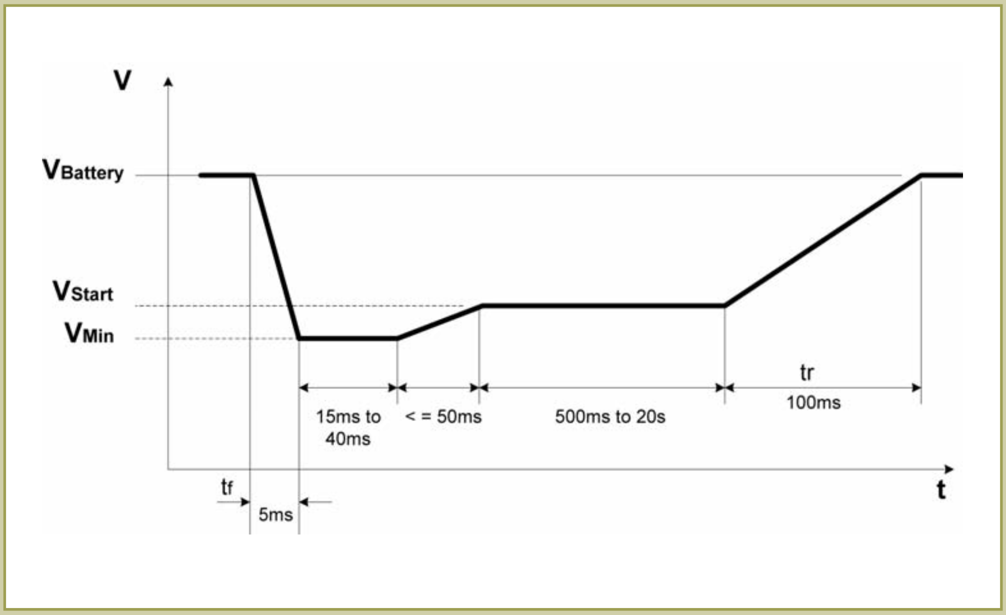


***Figure 1:** Cold crank profile of a vehicle battery*

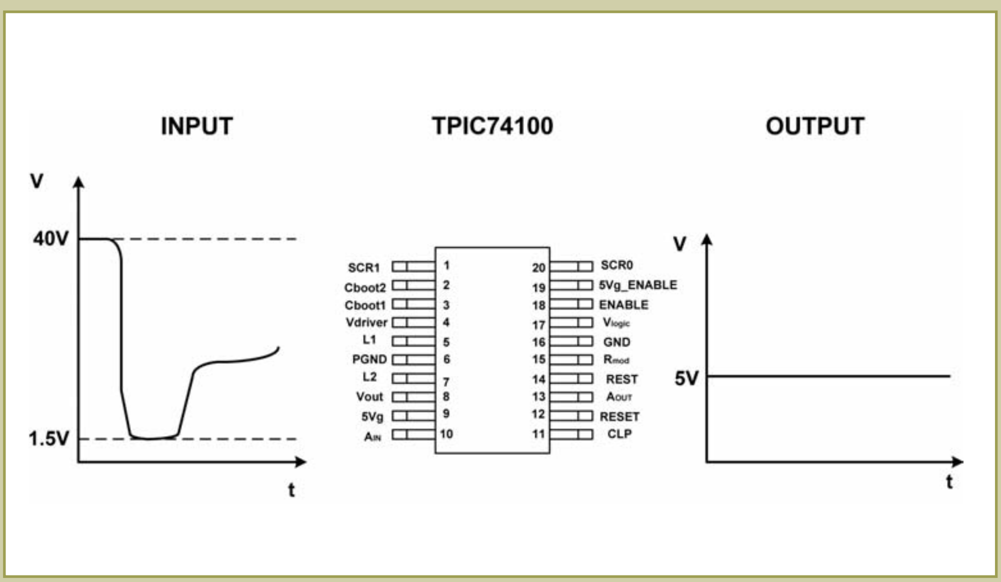


***Figure 2:** Output voltage during input voltage excursions*

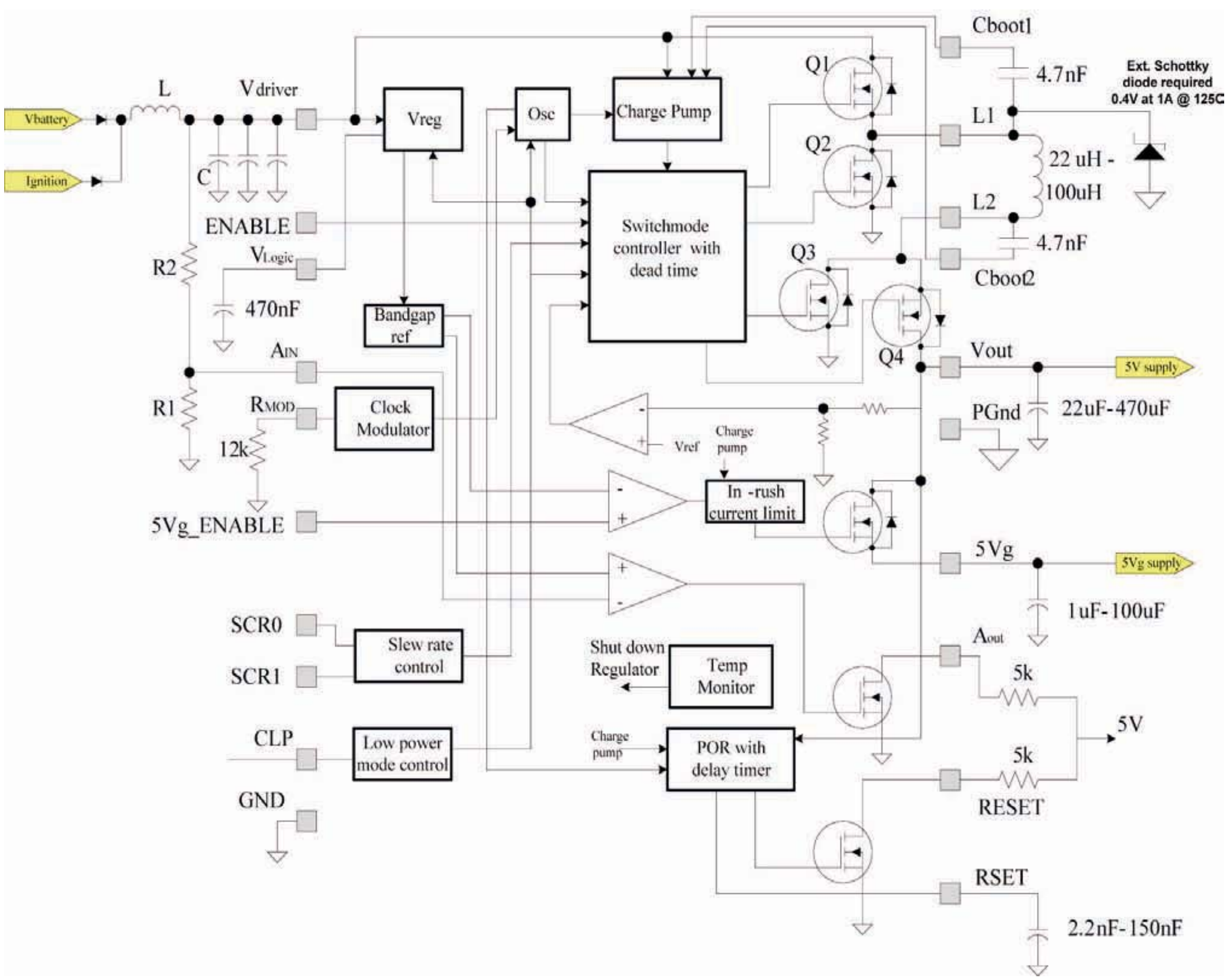


Figure 3: *Internal functional blocks*

Frequency spread spectrum using frequency modulation of not more than ±10% of the set frequency will not reduce the total emitted energy, but will distribute over the modulated frequency range. This method helps the system meet the FCC emission specification. This method also reduces the subsequent peak emitted energy for the sub-harmonics of the set frequencies.

Other factors to consider are related to power trace layout on the circuit board. Good practices include solid ground plane termination and isolation of noise sensitive pins (such as the feedback resistor node-to-ground from the power ground node). Also, minimise the current loop area for the current re-circulation path to minimise electrical and magnetic fields that could interfere with other circuits and components on the board.

During light load condition the converter operates in pulse frequency mode (PFM) to maintain low-current consumption and good overall converter efficiency. Additionally, there is a voltage supervisor that indicates if the output voltage falls below 93% of the output voltage.

EXTENDED RANGE OF CABLES AND ASSEMBLIES

Harting has extended its range of interconnection solutions with the introduction of several new standard and customer-specific cables and cable assemblies.

The standard product range now includes har-link (high-speed 2mm pitch connector) assemblies with two different types of shielding and hybrid cables with 3 x 2.5mm plus 4 x 2 data wires.

New customer-specific cable assemblies are now available for a range of connector types, including har-mik (MDR, SCSI), SEK (IDC flat cable connectors) and RJ45.

Also introduced are IP protected glass fibre optic assemblies and hybrid fibre-optic cable assemblies using the established Push Pull and Han 3A systems combined with high-quality outdoor cables.

The Harting Group develops, manufactures and distributes electrical and electronic connectors, network components, pre-assembled system cables, and backplane assemblies. These products are capable of withstanding the harshest demands in industrial environments and provide high data rates for electronic applications.

www.harting.co.uk

LIGHT AND RELIABLE PRINTING ON THE MOVE

Toshiba TEC Europe has launched two portable label printers: the B-EP2 and the B-EP4. These new high performance and robust portable thermal printers provide the ultimate in wireless functionality and reliability on the move.

Building on the success of the popular B-SP2D printer series, the new range of portable printers meets all the requirements necessary for integration into legacy systems therefore protecting customers' previous investments.

Ideal for every portable application, the B-EP2 and the B-EP4 offer USB and infra-red interfaces as standard and link quickly and seamlessly with other handheld devices.

With built in Bluetooth connectivity or secure wireless network (WLAN), communications are also available with specific models making the printers suitable for portable POS and remote transaction processing applications. And with added benefit of coreless media, the B-EP2 and B-EP4 are good for the environment too.

The B-EP2 and B-EP4 are Windows compatible, driven by a 32-bit flash-based CPU and are equipped with a full range of interfaces, a backlit LCD screen and key interface. They are also unique with their ability to allow users and administrators to change the settings and configurations directly on the device.

www.toshibatec-eu.co.uk

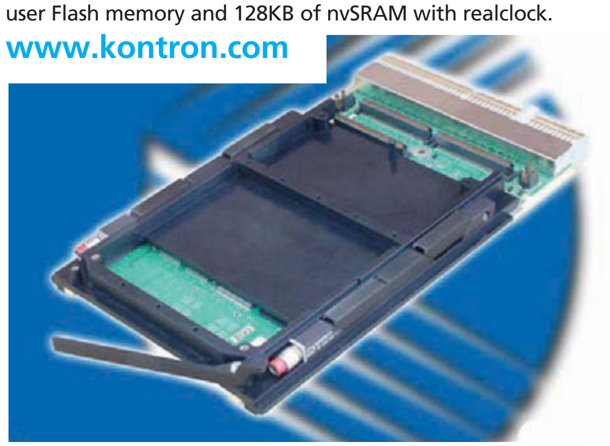
RUGGED CONDUCTION-COOLED 3U COMPACTPCI CPU

Kontron has presented its new PowerPC based Rugged Conduction-Cooled (RC) Kontron CP3210. With a faster clock rate of 733MHz, accelerated DDR SDRAM (266MHz, +33.3%), double the amount of system and user Flash and a Gigabit Ethernet port for faster data throughput and overall greater system performance, the Kontron CP3210 CompactPCI CPU board is an enhanced version of the highly reliable and powerful Kontron PowerEngineC7, a proven solution already embedded in major defense programs. Additionally, the new Kontron CP3210 incorporates a thermal sensor for health monitoring and thermal management.

Just like the Kontron PowerEngineC7, the new 3U CompactPCI CPU board is designed to meet the harshest and most demanding requirements through its very low-power dissipation, real-time and certifiable software support as well as rugged conduction cooled design.

The Kontron CP3210 CompactPCI CPU board offers an extensive range of standard functions and expansion options including the new powerful PowerPC G3 750FX RISC processor clocked at 733MHz, onboard user memory of 512MB DDR SDRAM with ECC clocked at 266MHz, 128MB of System Flash memory, 256MB of user Flash memory and 128KB of nvSRAM with realclock.

www.kontron.com



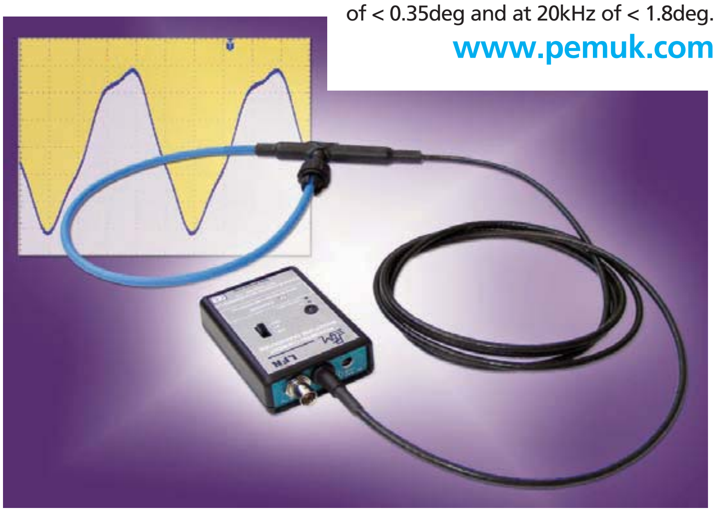
NEW LFR COMPLEMENTS CWT FROM PEM

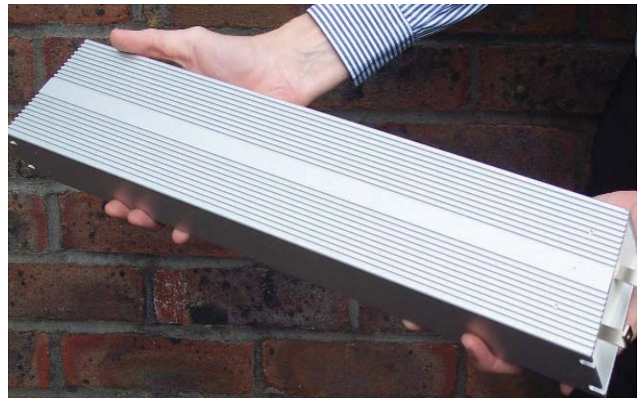
A new LFR AC current probe with market leading low frequency performance has been introduced by Power Electronic Measurements Ltd (PEM). This compact, low cost, clip-around probe is both flexible and dual-range, while being optimised to give minimal phase measurement error at frequencies from 45Hz to 20kHz. This is a Rogowski current probe, similar to PEM's highly successful CWT range, which covers 1Hz to 20MHz.

The LFR unit is ideal for use as a general purpose power frequency AC current probe and can be used with oscilloscopes, acquisition cards, data loggers, power analysers and meters. Other typical applications include power measurement, leakage current and power quality where minimal phase error, low noise and good accuracy are key measurement criteria.

All Rogowski current probes generate noise, but the noise floor of the LFR is very small, and the LFR1/15 model is only 2.0mVrms on the 300A range. The rated output voltage is 6V peak for a 300A peak current, thus at 20% rated current the noise contributes less than 0.1deg additional uncertainty to the phase error. This is better than a measuring class 0.5 current transformer. The same unit with peak current rating 300A/3000A and coil length of 300mm has minimal phase measurement error at 50Hz of < 0.35deg and at 20kHz of < 1.8deg.

www.pemuk.com





UL APPROVAL EXTENDED TO 2800W POWER RESISTORS

The 1600-2800W versions of the IRV series power resistors have just received UL approval. This now extends the availability of UL approval on this range of power resistors from 60W right through to 2800W.

The IRV1600-2800 models are very high power, wire wound, metal clad resistors.

The resistor elements of these models are fully encased in extruded aluminium housing which provides strong and rugged protection. Standard options for this resistor series include flying leads or tab terminals and inductive or non-inductive windings.

Custom options include: Flying lead terminations, internal thermostats and customer part number marking.

The most common applications for these models are: motor drive braking, high power snubber applications and power sources for industrial equipment.

These models are fully RoHS compliant.

www.rhopointcomponents.com

SIGNALMEISTER RF COMMUNICATIONS TOOLKIT SOFTWARE

Keithley Instruments has expanded its powerful SignalMeister software platform to now include RF signal analysis along with RF signal generation. First introduced in 2007, SignalMeister software is now the only software package on the market that integrates signal generation and analysis into one package for unmatched speed and simplicity.

Furthermore, SignalMeister now has the capability of generating and analysing both single-input single-output (SISO) and multiple-input multiple-output (MIMO) signals in the same environment. With SignalMeister software, research, design and test engineers can quickly and easily create and analyse signals with a powerful, yet easy to use, block diagram-based, graphical user interface. In addition, the SignalMeister RF Communications Toolkit now supports the latest wireless, MIMO protocol standards, WiMAX Wave 2 and 802.11n WLAN. It also provides additional complex functionality such as WLAN channel modeling, beamforming, simulation studies, along with a rich set of IQ operations, and full utilities for data import and export.

SignalMeister software also supports all standard-defined channel models for leading-edge WLAN 802.11n signals. Channel modeling defines the various multi-path scenarios that must be tested for device certification

To learn more about Keithley's SignalMeister RF Communications Test Toolkit, visit **http://keithley.acrobat.com/signalmeister3**

TESTER FOR BROADBAND LINES OVER COPPER CABLES

The new Trend Multipro Copper tester verifies that the twisted pair cables to the office or home have the required bandwidth of up to 30MHz to carry the new high-speed data services such as VDSL.

The portable and rugged instrument measures cable characteristics before installation to determine whether the cable would degrade service performance. The Trend Multipro Copper now enables carriers to install high speed lines up to 5km from the exchange so opening up higher speed broadband Internet, including TV, to many users.

The Trend Multipro Copper contains a collection of test functions to test, diagnose, analyse and measure cables, it is aimed at installers and maintainers of VDSL – the next step up from ADSL. Tests include frequency response, return loss and noise. Diagnostics cover crosstalk, induced voltages, interference and noise. Analysis is carried out using the integral spectrum analyser, oscilloscope and time domain reflectometer.

Measurements include capacitance and insulation.

One major advantage is that the operator can measure all the parameters of a cable from the near end to the far end using an optional transponder located at the far end.

www.trendcomms.com

OPTIMUM PROTECTION ROCKER SWITCHES

A new switch solution for applications in a humid, wet and dusty environment has recently been introduced by Tyco Electronics. New PRC series power rocker switches provide an optimum protection against dust and liquids and are quick to install.

PRC series switches are sealed to IP66 and feature easy to install snap-in mounting to a 21.2 x 36.6mm panel cut-out. Available in SPST, SPDT, DPST and DPDT contact configurations, the new switch devices provide screw, solder or quick connect terminals as well as various rocker markings (as standard).

Fully RoHS compliant, PRC series switches are rated 20A at 125VAC and 10A at 250VAC. Mechanical life is 100,000 operations minimum. Actuation force is 400 up to 2900g and the operating temperature range is -20 up to +80 degrees Celsius.

The devices are ideal for applications such as industrial machinery, lighting (e.g. kitchen light for working place), HVAC equipment, outside power supplies, gardening tools, dry and wet vacuum cleaner, high pressure cleaner and boat industry.

www.tycoelectronics.com

KM6-II SUBRACKS AVAILABLE FROM SURTECH

Surtech Distribution, the enclosures and accessories specialist, has announced that it has been appointed main UK distributor of the "gold standard" in subracks: the KM6-II, manufactured by HDD of Bremen, Germany. The KM6-II is well-established as the market leader, renowned for having an unbeatable combination of versatility and cost-effectiveness: more the subrack has been continuously updated in line with technological advances.

Surtech can supply the KM6-II in kit form or fully assembled configured to specific customer requirements. Technical help is available through Surtech's dedicated technical sales team, who have the expertise to advise customers on the most cost-effective product for their particular needs. Additionally, Surtech offers a complete modification and customisation service for KM6-II subrack front panels to suit specialised or unusual applications.

KM6-II subracks are available in two versions: KM6-II Standard, which is optimised for 160mm and 200mm, 3U and 6U eurocards; and KM6-II Universal, which is suitable for 3U, 4U, 6U and 9U applications. With end plates up to 420mm high, the KM6-II Universal is extremely versatile and can be configured in many different ways as there are literally hundreds of parts and accessories available.

www.surtechdist.co.uk

VG95234 CONNECTORS AVAILABLE WITH 48-HOUR ASSEMBLY SERVICE

VG95234 multi-pin circular connectors manufactured by ITT Interconnect Solutions (Cannon and VEAM) are now available from franchised assembling distributor PEI-Genesis with its market-leading 48-hour assembly service.

Designed in accordance with the VG95234 specification, the connectors use the dimensions and contact arrangements laid down in MIL-C-5015, but instead of being threaded they are provided with a reverse bayonet coupling mechanism, which offers exceptional vibration-protected sealing against fluids, as well as easy connection/disconnection.

Capable of withstanding the most severe conditions, the VG95234 connectors feature aluminium-alloy shells with an olive drab finish, high-quality polychloroprene insulators and silver-plated copper contacts with maximum current ratings from 8A to 245A.

These rugged waterproof connectors are particularly suitable for industrial, transportation and military applications and are available in a wide variety of shell styles, sizes and contact arrangements. Operating temperature range is specified as -55 to 125degC. The connectors are rated for a minimum of 500 mating cycles.

www.peigenesis.co.uk

CLARE ADDS FLASH TO PCB TESTING

PCB manufacturers can take advantage of a fast, reliable and safe solution to meet the growing demand for flash/HIPOT tested (2kV) unpopulated boards.

Electrical safety testing specialists Clare Instruments has developed a bespoke system utilising its HAL H101 instrument connected to a test enclosure which enables the easy flash testing of PCBs during the initial production stages.

The enclosure has a conductive foam base with modular sections to accommodate different sizes of PCBs. It can have either a spring mounted probe system or a further section of conductive foam can be added to allow it to work with different types of PCBs.

The move follows an increasing US-led trend that all base PCBs must now be flash tested during the manufacturing process to ensure that they have no defects and are compliant with safety standards.

This comes from growing demand among global component assemblers that all electronic components should be able to pass a flash test before final build.

Two types of PCB can be tested: those with one surface covered in metal and 'standard' units with an insulated side.

www.clareinstruments.com

COST-EFFECTIVE COMPONENT TEST SOLUTION

Keithley Instruments announced the ACS Basic Edition, characterisation and curve tracer software for component test applications. The latest addition to Keithley's powerful Automated Characterisation Suite (ACS) family, ACS Basic Edition integrates with the industry's broadest range of source-measure units, Keithley's SourceMeter Instrument family. ACS Basic Edition, pared with Keithley's proven line of SourceMeter instruments, replaces obsolete curve tracers with a solution that performs both basic curve tracing as well as parametric test while providing a remarkable cost breakthrough. Keithley first introduced its ACS integrated test systems in 2007 as highly configurable, instrument-based systems for semiconductor characterisation at the device, wafer, or cassette level, offering unique measurement capability with powerful and flexible automation-oriented software. Initial ACS systems were designed for larger semiconductor lab applications that call for a probe station and large-scale on-wafer test applications. ACS Basic Edition is targeted for bench-top component test applications that don't require integrated probers yet still need the measurement and software automation power provided by the ACS platform. ACS Basic Edition is available immediately; to learn more, visit:

http://keithley.acrobat.com/acsbasic/

OPTICALLY CLEAR STABILISED FILM

ICI Imagedata launched Stabilex Ultra Optically Clear stabilised film at the Printed Electronics Show 2008 in San Jose, California (3-4 December 2008). ICI Imagedata is expanding its Stabilex Ultra range of thermally stabilised films with the launch of this new Optically Pure Film.

Thanks to a unique purpose-built thermal stabilisation system, Stabilex Ultra Films offer excellent product quality, consistency and performance, making them ideal for a wide range of electronics applications. A continuous roll-to-roll stabilisation process effectively eliminates the inherent thermal instability of the extruded film whilst controlling its skew and lay flat properties.

The new Optically Clear Film, which has been designed to satisfy the most demanding display and photovoltaic applications, enhances the existing Stabilex Ultra range of clear, white and translucent films.

With electronic displays and photovoltaic cells, it is vital that light is transmitted efficiently without loss or scatter. Stabilex Ultra Optically Clear Film provides excellent light transmission with a haze of less than 0.5%. What is more, because the ICI Imagedata manufacturing process uses a cushion of air to transport the film, the risk of microscratching is virtually eliminated.

www.ici-imagedata.com

VERSATILE USB CONNECTOR FAMILY AVAILABLE EX-STOCK FROM HARWIN

High-reliability interconnect company Harwin has announced that its new range of Universal Serial Bus (USB) connectors are immediately available off-the-shelf in a wide variety of formats to suit differing customer requirements. Applications include laptops/PCs, digital cameras, set-top boxes, PDAs, camcorders, industrial equipment, office automation and medical devices.

The competitively-priced USB connector family includes: USB A PC tail vertical and horizontal; USB B PC tail vertical and horizontal; and USB B and Mini USB styles.

The USB I/0 comes either as a single or double-decking configuration. Between 4 and 8 pins are available depending on connector configuration. The range is fully RoHS-compliant and is available in selectively plated gold finish. A metallic outer shell provides good shielding for signal integrity.

USB is an industry-standard interface used in a variety of consumer and industrial applications. This new connector range from Harwin is designed to provide development engineers with a great deal of flexibility to suit their designs when installed on a PCB.

www.harwin.co.uk

FIREWIRE CONNECTORS AVAILABLE EX-STOCK FROM HARWIN

High-reliability interconnect company Harwin has announced ex-stock availability on a range of competitively-priced Firewire (IEEE 1394) connectors capable of transferring data between devices at 100, 200, or 400Mbit/s. Two styles are available in the range: a six-pin version that provides power handling and a reduced size four-pin device.

Connectors feature a female surface mount configuration combined with through-board hold down tags providing a secure mounting to the PCB. The range is fully RoHS-compliant and available with a selectively-plated gold finish.

A metallic outer shell provides good shielding for signal integrity. Current rating per pin is 1.5A, devices are voltage proof to 500V AC, contact resistance is 50mΩ and insulation resistance is 1000MΩ. Operating temperature is -40 to +85degC.

These new devices fully conform to the requirements of IEEE 1394, and they offer a great deal of flexibility.

Harwin is a manufacturer of standard and custom interconnect components. From its UK headquarters, Harwin has been successfully manufacturing electronic components for more than 50 years. Products include: high reliability devices, RFI and PCB hardware, and an extensive range of industry standard interconnection solutions.

www.harwin.co.uk

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2236A	Dual Trace 100MHZ Dual TB with Counter Timer & DMM	£195
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2465B	Rack Mount 4 Ch. 400MHZ Delay Sweep. Cursors etc	£400
2467	4 Ch. 350MHZ Delay Sweep. Cursors etc	£400
TAS 465	Dual Trace 100MHZ Delay. Cursors	£195
TAS 485	4 Ch. 200MHZ Delay. Cursors	£275

HP

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54600B	Dual Trace 100MHZ 20 MS/S	£225

PHILLIPS

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PM3065	2+1 Ch. 100MHZ dual TB/Delay. Autoset	£125
PM3084	4 Ch. 100MHZ Delay TB	£140
PM3335	Digital Storage Dual Trace 60MHZ 20 MS/S	£125
PM3337	Rack Mount Digital Storage Dual Trace 60MHZ 20 MS/S	£125
PM3365A	Digital Storage Dual Trace 100MHZ 100 MS/S	£150

HITACHI

V222	Dual Trace 20MHZ DC Offset, Alt. Mag	£50
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HAMAG

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Increased Focus on Power Supplies and DC/DC Converters

Arrow Electronics has expanded its power technology portfolio by signing a distribution agreement with Recom, a leading global supplier of DC/DC and AC/DC converters. Arrow will sell and support Recom's complete power converter product range throughout Europe.

The new agreement is in line with Arrow's strategy to provide the widest possible range of power supply and converter technologies to designers across Europe. For Recom, the agreement will expand the penetration of its product ranges into European markets and ensure that customers have access to products and support at a local level.

Available in single, dual, and triple rail outputs and a wide variety of input and output voltage configurations, power ratings, and isolation voltages, Recom converters are used in most industries requiring low- to medium-power voltage conversion in the 0.25W to 60W range. The company also offers the largest range of safety agency-approved converters from any manufacturer.

www.arrowne.com

Harwin in an Exclusive European Trio-Tek Catalogue Sales Agreement with Farnell

High-reliability interconnect company Harwin has appointed Farnell as exclusive European catalogue distributor for its innovative Datamate Trio-Tek range of crimp contact connectors.

Harwin's Datamate Trio-Tek open-barrel crimp contact offers significant advantages over conventional Datamate contacts whilst providing the same high reliability, as it enables assembly time to be shortened significantly and therefore reduces processing costs. The new crimp design features a triangular form that simplifies the insertion of contacts into the housing, enabling customers to fully automate crimping in medium and high volume applications.

Harwin's Datamate Product Manager Graham Cunningham commented: "Farnell is one of Europe's leading distributors and justifiably known for offering customers an extensive range of the best products and latest technology from leading manufacturers. We have a strong relationship with them and believe their reputation for first-class customer service and the strength of their catalogue media will provide an excellent partner for Trio-Tek. We are delighted to have appointed them as our catalogue distributors for this important initial phase of Trio-Tek sales in Europe."

Farnell's Justin Willoughby said: "We have a long and fruitful relationship with Harwin and always welcome the opportunity to offer their latest products to our customers. Harwin's expertise as a global leader in the design and manufacture of electronic interconnect solutions means their products are always leading edge and provide elegant solutions for electronics engineers across a great number of applications and markets."

www.farnell.co.uk
www.harwin.co.uk