Racing ahead

The challenges of developing an engine control unit for use by all F1 teams. By **Graham Pitcher**.

The name McLaren has a long heritage in Formula 1 – only Ferrari has been in F1 for longer. Established by New Zealander Bruce McLaren in the mid 1960s, McLaren has since diversified into road cars and set up an applied technologies group. It also established an electronic systems organisation focused on motorsport. McLaren Electronic Systems (MES) now supplies engine control units (ecu) to all F1 teams, as well as to competitors in the US NASCAR and IndyCar series. It also develops and supplies a range of telemetry and sensor equipment.

Tim Strafford, business development manager for MES, was a control systems engineer with the McLaren F1 team. In his early days with McLaren, he was involved in the development of control strategies for the F1 car, including traction and launch control. He also developed a seamless shift gearbox control strategy, in which gear engagement is timed to an accuracy of 100μs.

With seamless shift, the next gear is engaged before the last one disengages. "This has to be timed to 0.1ms," said Strafford. "And we have to avoid partial engagement, otherwise the engine's full power will be transmitted through a small area and it will all go 'bang'."

MES introduced its first F1 control system in 1993. "The intention was to develop electronics for the McLaren F1 team," he continued. "Electronics was seen as a differentiator; if you had the best electronics, you would get a performance advantage." Strafford recalled the period as being something of an 'arms race'. "We were all developing strategies such as launch control and traction control. If the FIA regulations allowed something, it was a race to develop the best strategy."

It was a period of intense activity. "We developed a new control strategy in the morning," Strafford continued, "tested it on hardware in the loop equipment, then released the code and ran it on the car in the afternoon."

The Federation Internationale d'Automobile (FIA), motor sport's governing body, decided it had to level the playing field. "It had tried a number of approaches to police things, with various levels of success," Strafford recalled. "It decided to require all teams to use the same ecu to make it easier to ensure what they were doing was legal."

The FIA opened a tendering process for companies to supply ecus to all F1 teams for the 2008 season. MES won the three year contract, which was extended for a further two years.

McLaren originally ran the TAG-310, a precursor to the standard ecu, in 2005. "That ran on the car for a year, but was large compared to the current version," Strafford noted. McLaren's technical director at the time wanted a smaller version that sat beneath the driver's legs to help with the aerodynamics. The current version – TAG-310B – is a six sided box measuring 167 x 162 x 56mm. It communicates with the car using three 100way connectors.

The ecu is at the heart of an F1 car, providing complete control over the powertrain. It works with slave units to control ignition and injection for a V8 engine, as well as controlling throttle by wire and clutch by wire functionality. In order to do this, it takes data from something like 130 sensors around the car. Accuracy is crucial; F1 engines run at up to 18,000rpm and the control strategy can recognise crankshaft positions to an accuracy of 0.027°.

Along with general purpose 10bit and 12bit analogue inputs, the ecu receives data from inductive and Hall Effect speed sensors, thermocouples and a lap trigger interface. Outputs go to such devices as drive stages, ignition control and transducer power supplies.

Routing all this information around the car at the data rates needed is not trivial. Hub interface units (HIU) mounted on the wishbones at each corner of the car take data from the wheels and route it back to the ecu via CAN.

There are six CAN buses in the TAG-310B; the forthcoming TAG-320 will have 11. "An F1 car very occasionally suffers from loose wires or damaged connections," Strafford said, "so we need multiple buses. Each CAN bus runs at 1Mbit/s, so we can get high bandwidth data to the ecu."

Each rear wheel has two speed sensors. One feeds data into the HIU, but

Photograph: Charlie Milligan

the other links directly to the ecu. "In this way," Strafford continued, "we can measure driveshaft twist – and hence torque – even though the speeds are monitored in different places." This approach requires careful timing management. "The ecu hosts all timing," Strafford explained, "and distributes it to the units that need it."

With such complexity, distributed processing was considered. "We tried it," Strafford said. "Each time we added another box with a high speed link, we needed to further break up the control strategy. There were more boxes, more wires and more complexity.

"When you move to a distributed system, it becomes more difficult and you have to deal with the possibility that you lose communications between the boxes. However, we do design in resilience."

One improvement to the ecu relates to the analogue inputs. "Previously, these went to analogue filters and then to a/d converters sampling at 1kHz," Strafford said. "Given the nature of the control strategy, we couldn't afford to have latency; it wasn't fast enough for full antialias filtering."

Filtering is an important issue. "Sometimes, we have a pressure sensor mounted on an engine, so vibration is superimposed on the signal. We had to make different ecu variants with different filter behaviour because customers had different requirements. With our next generation ecu, we sample all analogue inputs at 80kHz, with digital filtering performed in an fpga. This multistage filtering process supports the different rates needed by different sensors and control strategies."

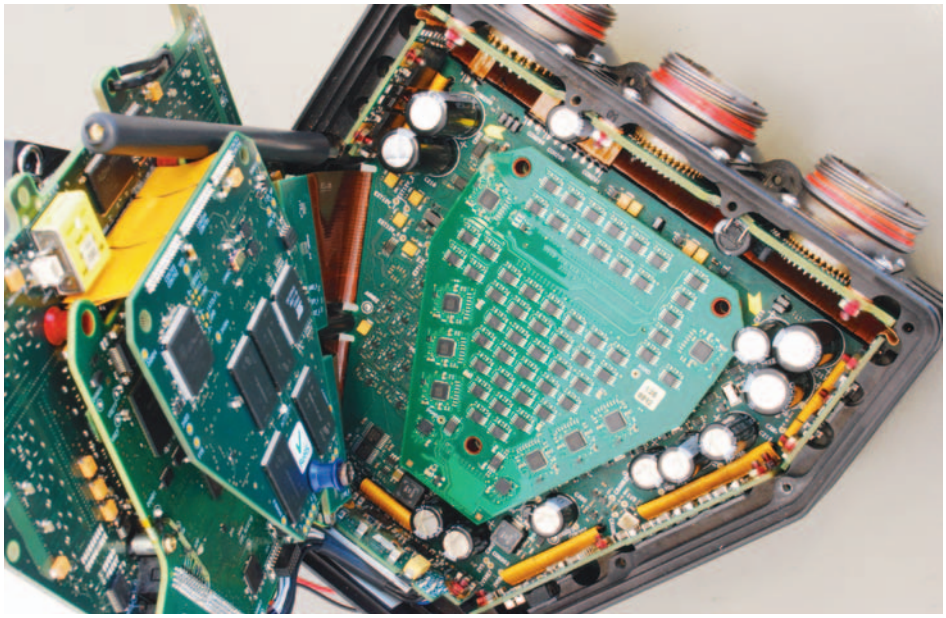
The ecu's main control strategy runs on a 1ms time step. "As a control engineer," Strafford observed, "you want determinism of the signals you're picking up at the beginning of each 1ms window; you don't want latency and you don't want jitter." The fpga solves this problem by managing the process. "It sends the data over a PCI-Express link to DDR memory local to the processor. The processor then gets an interrupt saying 'start running the control loop'," he explained. "We need the fastest possible access to data and now it's in local memory."

Now, the ecu is being developed to take account of changes in F1 regulations. "When we started supplying F1 teams," Strafford said, "we knew there might be a different powertrain in the future and wanted to develop an ecu that could support it."

The FIA issued another invitation to tender to supply F1 ecus from 2013 to 2015. MES won the business and has developed the TAG-320. But there has been a problem. "The new engine regulations have been delayed for a year," he said. "So the TAG-320 will be handling V8 engines for a year, then V6 hybrids. It's a flexible system which can run current and future engines; just the software changes."

Creating an ecu for F1 applications is akin to pouring a quart into a pint pot. The TAG-320 has some 4000 components mounted on 11 rigid and flexible pcbs, some of which have 20 layers. Because the ecu's footprint is a rectangle with cut off corners, components are not laid out in a normal X-Y fashion; some are on a slant. "We have squeezed a lot into the system and even rectangular boards of the same area would have been a challenge because of the component density," he said. Another change is in processing power: the TAG-310 boasted 900MIPS, but the TAG-320 has 4000MIPS available.

Development of the TAG-320 started in 2008 from a 'blank sheet of paper'. The approach, said Strafford, was to optimise the design around the



requirements of the control strategies. "This drives architecture, analogue sampling rate, control loop step time and the amount of processing required."

ECUs for F1 cars are significant cost items, so design isn't iterative. "We have developed a 'right first time' culture. Engineers may take longer to do the design, but they're not wasting time; they are making sure every component is within spec in all conditions. For example, routing the main processor board took one person-year. Once the design is handed over, designers are confident it will work."

One of the challenges was to maintain the same form factor. "There were good reasons for this," Strafford said, "but it didn't make the design task any easier." Because of this, the design needed to include flexirigid pcbs. "Previously, there were a lot of ribbon cables, which could route into the pcbs at any layer. With the flexirigid approach, we ended up taking more space with vias in order to get signals to the right places." Yet flexible pcbs bring their own issues. "Although we have optimised the use of space, we also have to consider such issues as bend radius and design for manufacture," Strafford added.

Even careful design can't mitigate against obsolete components and this required a board revision. "It allowed us to implement a new technique which gives resilience," Strafford pointed out. "We now use standard interfaces to memory; the processor now talks to something resembling a usb memory controller. Even if devices become obsolete, the interface remains the same and the software doesn't have to change."

Developing the code to run on the ecu is not trivial. MES has used Simulink since 2000. "We have been supported by The Mathworks, but have had to do a lot of work to manage the large and complex control strategies," Strafford explained.

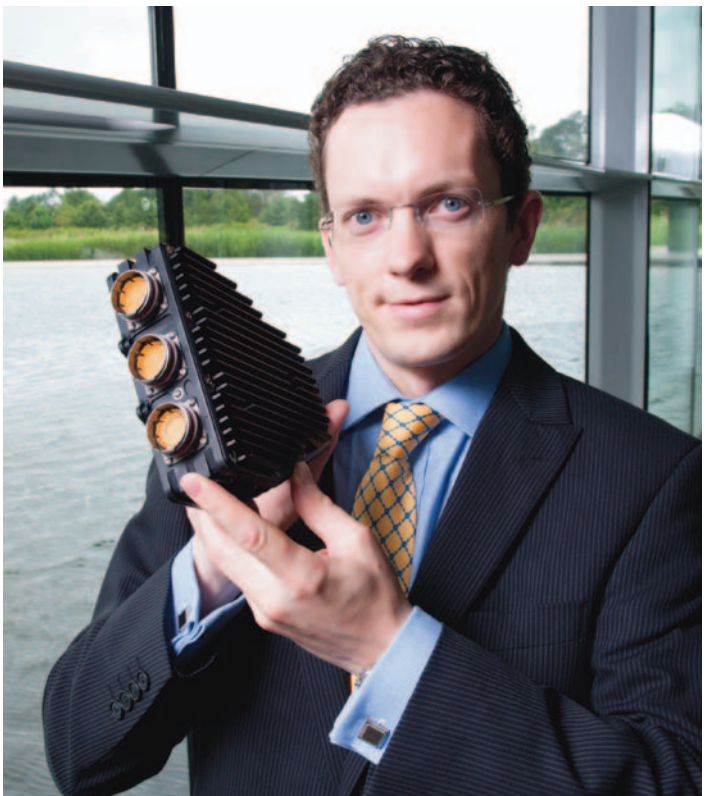
One change from the previous model is to provide the ability for F1 teams to run their own code alongside mandated applications. "We wanted to offer the best of both worlds," Strafford said.

With this approach, each application runs in its own address space and can only access certain signals. "For example, traction control is blocked by not allowing the routine to access wheel speed data," Strafford noted. "It's the FIA that gives permission to access the various data."

The TAG-320 features two dual core Freescale processors, each with local DDR memory. Data is shared using PCI-Express and RapidIO; both featuring four lanes transferring 2.5Gbit/s in each direction.

Although early software development was carried out on evaluation boards, MES had to do some quick thinking to enable communication between the two systems. "We have two processors, so we used two eval boxes," said Strafford. "But the eval systems were not designed with RapidIO in mind. However, we found a PCI-Express card with a ribbon connector that could link the two systems and built a system with two dual core processors talking over RapidIO. We did a similar bridge to the fpga. Our approach was to use hash defines and similar techniques where things needed to be different between the 'real' and eval systems."

F1 is often a proving ground for technology. "The electronics in the McLaren MP4-12C road car incorporate technology and techniques from F1," Strafford concluded, "and it's something we're going to see more of from other manufacturers.



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