how it works

COMPONENTS OF YOUR FUTURE CAR RACE IN FIVE CONTINENTS.

The racer's edge

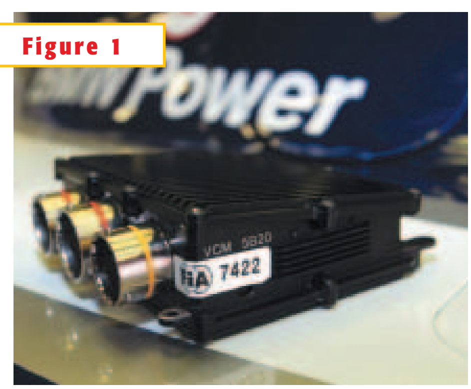
By Gabe Moretti, Technical Editor

FORMULA ONE, OR F1, as most people call it, is the most technologically advanced form of car racing in the world. Although not as popular in the United States as other types, such as NASCAR and IRL, for example, Formula One is second only to soccer in the number of people following it worldwide. The sport has always demanded the utmost commitment to technological innovation from its participants. Many of the technologies used in today's consumer cars were first used in F1 cars, from engine management to vehicle control. In fact, engineering developments in F1 have such a direct impact on the components of commercial vehicles that American car manufacturers have joined Japanese and European companies as participants in the F1 World Championship. Ford competes in F1 through its Jaguar division, and Chrysler partners with McLaren through Mercedes-Benz. General Motors is the only American company without direct involvement, but it has an indirect link to the technology through its partnership with Fiat, which owns Ferrari, the constructors' world champion for the past three years.

Currently, there are half a dozen electronics-control modules in a Formula One car, and the VCM (vehicle-control module) plays a critical role in the car's performance. Xilinx is a technical partner of BMW Williams, this year's runner-up for the constructors' championship. The company provided much of the material for this article. VCM functions include shifting gears, controlling traction, controlling launch, gathering data, and transmitting data in real time.

The main components of the BMW Williams VCM in the 2003 competitions were a Texas Instruments DSP and a Xilinx Virtex-E XCV600E FPGA (**Figure 1**). Given the amount of processing that race conditions require, engineers must increase the processing power of the VCM by supplementing the DSP with more hardware to meet the data-logging requirements and to control high-speed hydraulic actuators used in the car. In choosing an architecture for the VCM, the BMW Williams team rejected the use of a microcontroller to offload some of the processing demands on the DSP because of the need to write software and maintain the code base. In addition, the software-inspection demands imposed by the FIA, the governing body of F1, make the use of a microcontroller even less desirable. Rules change frequently in F1 racing, and teams must be able to respond quickly with competitive solutions that meet every new detail. Solutions based on FPGAs provide both the necessary flexibility and the required computing power. For 2004, the BMW Williams team plans to replace its current FPGA, which has reached 85% usage, with a Virtex-II Pro platform that includes an onboard multiply-and-accumulate block to increase the processing capabilities of the VCM.

Figure 1



The FIA seals each VCM after inspection.

The VCM handles approximately 220 channels of data at rates as high as 1 kHz. As many as 90 of these channels carry signals from sensors used to analyze the car's performance over an entire race or test session. Some channels monitor the actions of the control software, and others monitor the driver's inputs. The BMW Williams unit stores as much as 256 Mbytes of data on a Compact Flash card mounted permanently inside the VCM. Another team has increased the storage capacity of its VCM to 500 Mbytes, an indication of the ongoing competition for excellence in technology. After the race, technicians download the recorded data by wire link for analysis. The VCM also transmits a subsection of the logged data via serial link to a telemetry transmitter on the car. The real-time data permit engineers in the pits to observe the behavior of the car and of the driver and alert them to any impending problem.

Reference 1 shows an entire lap's worth of telemetry transmitted from driver Ralph Shumacher's BMW Williams car during the Sept 28, 2003, US Grand Prix in Indianapolis. Real-time data collection is important to a team that wishes to be competitive, because each track has different characteristics, and each team must prepare its car to optimize performance according to the characteristics of each venue. A track with long straightaways and few curves requires the car to have little down force; a track with many curves requires significant downforce. In most cases, teams each year build a new version of the racing car, but engineers use valuable data from the previous year's event together with the aerodynamic data for the new car to determine the new car's initial setup.

The VCM performs a number of data-analysis and -reduction functions to communicate real-time information to the driver by controlling a number of signals and warning indicators. The VCM embeds functions to detect the failure of sensors onboard the car. The output of these functions prevents the control algorithms from using failed sensors and allows teams to quickly identify problems. The VCM monitors inputs from multiple sensors and acts on the majority decision in each case. The importance of the function determines the level of redundancy.

The gear-change sequence in an F1 gearbox requires precise control over the positions of the gearbox actuators, as well as controlling the clutch and coordinating engine revolutions per second with the engine controller. Because a competitive F1 engine can reach 19,000 revolutions per second, and a typical gear change takes less than 50 msec, even the smallest of errors has catastrophic consequences. The system must also guard against driver error, such as if the driver selects the wrong gear. During the 2003 racing season, the VCM was allowed to initiate gear changes without driver input as a consequence of values obtained from sensors on the wheels and from the engine-control module. The FIA has outlawed automatic gear changes for 2004, requiring drivers to manually initiate each gear change. Once a driver has initiated a gear change, the VCM will be allowed to handle the remaining sequence of functions.

Although many commercial cars are equipped with traction control, F1 cars use a version that not only reacts to, but also predicts vehicle behavior. It is not unusual before the start of a race to see a team member connecting a laptop computer to a car. The technician is updating the parameters of the tire model by inputting the latest track-surface and ambient-temperature values and the description of the final suspension geometry selected during the warm-up laps. The team also checks and updates the coefficient of abrasion for the track surface, as well as the mechanical and dynamic characteristics of the tire mounted for the race. The VCM performs calculations based on sophisticated computer models of the tire type mounted on the car to predict the amount of wheel slippage required to achieve maximum traction and minimum wear. The VCM calculates control target values and inputs the data to the engine controller. In addition, the VCM generates control signals for the hydraulically actuated differential, aiming to provide maximum traction from each of the rear wheels to optimize the stability of the car when cornering.

Contrary to most forms of US car racing, which employ a rolling start, F1 races begin with a standing start. The cars perform one reconnaissance lap and then stop on their assigned start-grid positions. The starter lights five red lights in sequence, and the race starts when the lights go off simultaneously. An F1 car can accelerate from a standing position to 100 mph in less than three seconds; avoiding wheel spin is critical to a good start. Teams employ launch-control systems to ensure an optimum start. The VCM communicates clutch- and engine-target values to the engine controller to avoid wheel spin and to provide the best acceleration possible for the car. Although the FIA may prohibit this function in the future to restore a greater role for the driver in winning a race, the technology may find its way into commercial vehicles. One goal may be optimizing the power/fuel-consumption ratio during starts. Considering the number of stop-and-go situations that commuters in metropolitan areas encounter, such a system may pay for itself in a short time by reducing both fuel consumption and tire wear.□

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