Single-Chip Digitally Controlled Data-Acquisition as Core of Reliable DWDM Communication Systems

by Mark Malaeb [mark.malaeb@analog.com]

The recent lifting of government regulations on the communications industry has fueled an explosion of new ideas and inventions, especially in the optical space. Many players, from startups to Fortune 500 companies, participated in the 1998 to 2000 growth period in an attempt to implement these ideas. Today, although the industry is going through a painful period and many of the startups are gone, the need for implementing these ideas and inventions is still alive and well.

Optical fiber is the transport medium that has emerged to accommodate the expected long-term growth. In order to make the most of the wide bandwidth, which is the principal advantage of fiber transport, a method called *wave-division multiplexing* (WDM)—and later, *dense* WDM (DWDM)—was implemented. This method of transmission allows the transport of multiple wavelengths (one wavelength—or color—per laser) through a single fiber, but imposes stringent requirements on lasers.

One major requirement is that the laser temperature be held constant so that its wavelength will not drift and interfere with other lasers. This usually involves a *thermoelectric-cooler* (TEC) controller (addressed later in this article). Controlling the laser power level and its modulation mechanism over time and temperature is another system requirement. This job is handled by the *laser-diode driver* (LDD). For long-haul applications, optical amplifiers are needed for signal reconditioning and retransmitting. *Erbium-doped fiber amplifiers* (EDFAs) and Raman amplifier types predominate. They recondition the signal without having to convert it from optical to electrical, and then back to optical—which was the widely used method (and only option) in the past. The amplification is now done solely in the optical domain. However, to control their parameters, optical amplifiers, need high-end *A/D and D/A converters* (ADCs and DACs), logarithmic amplifiers (log amps), and *transimpedance amplifiers* (TIAs), plus a controller.

Optical Communication Systems

Most optical communication systems (Figure 1) use ADCs and DACs in the control loops used for the *thermoelectric cooler* (TEC), laser diode driver (LDD), and *avalanche-photodiode* (APD) monitoring and biasing circuitry. Dedicated control loops are used for driving the pump laser and reading its power level; adjusting the *extinction ratio* and *average power* in the transmit laser diode; and maintaining the laser diode at a stable temperature in WDM and DWDM systems. Loop signals are digitally processed by a *microcontroller.* Containing all these tasks in its portfolio, the ADuC832, a member of the MicroConverter® family—an integrated data-acquisition chip, combined with a CPU core and standard peripherals—is a strong candidate to serve as the heart of such control systems.

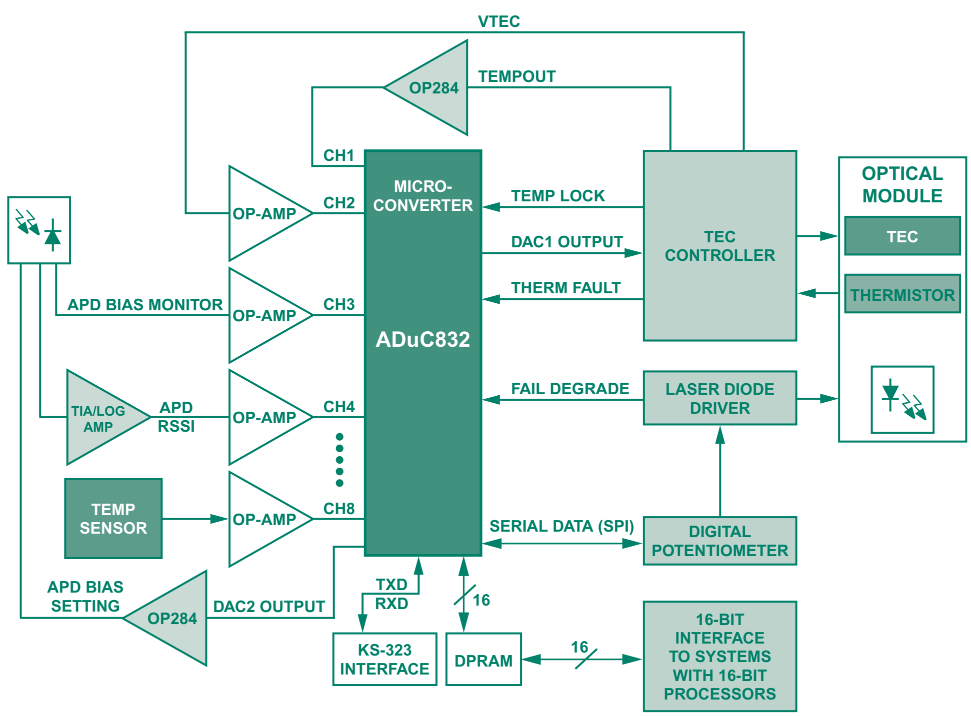

Figure 1. Overall system block diagram.

The ADuC832 (Figure 2) includes: an 8-channel, 12-bit, 5-µs self-calibrating ADC; a 2-channel, 12-bit DAC with rail-to-rail outputs; an industry-standard 8052 microcontroller; 62 Kbytes of Flash program-RAM, and a host of peripheral functions. All of these features, plus a temperature monitor, programmable PLL clock, voltage reference, synchronous and asynchronous serial ports—and more—are integrated into a space-saving 56-lead *chip-scale package* (CSP), allowing the entire control system to fit within the housing of an optical module.

We describe here the possible practical implementation of the various portions of an optical communication system, as shown in Figure 1, including a thermoelectric-cooler controller, laser-diode drivers (LDDs), photodetector-diode biasing, received optical signal-strength indicator (RSSI), and temperature sensors.

Complete, fully tested software modules are available for each of these applications. These modules are written and commented especially for analog/optical designers who are not software savvy and never want to be. This will help cut design time and overall time to market for both experienced and novice programmers.

TEC Controller

To ensure wavelength stability, the thermoelectric-cooler (TEC) controller is designed to maintain a laser diode or optical module at a specific temperature, with precision typically to within 0.01°C. This device relies on a negative-temperature-coefficient (NTC) thermistor to sense the temperature of the object attached to the TEC. The target temperature is set with an analog input voltage—either from a DAC, as shown in Figure 3, or with an external resistor divider. A positive or negative current is applied to the TEC, either heating or cooling the object as required. An internal proportional-integral-derivative (PID) compensation amplifier stabilizes the temperature. An external PID network can be adjusted to optimize the settling time.

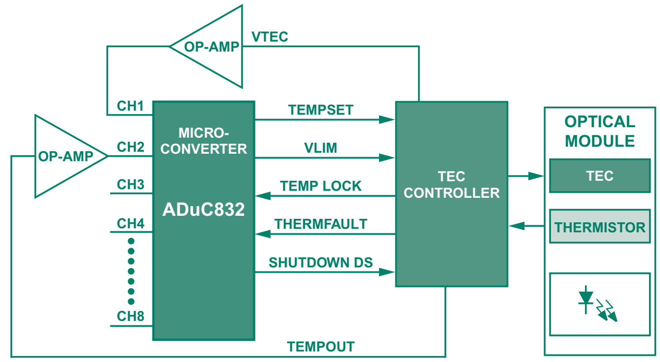

Figure 3. The MicroConverter sets the TEC target temperature and monitors its performance.

One of the 12-bit DACs, connected to the TEMPSET pin, sets the target temperature. The voltage corresponds to a specific target temperature (typically 25 mV/°C for most laser diode applications). The TEC, through its PID loop, maintains the target temperature to within 0.01°C (naturally, this value is dependent on the thermistor quality and suitable care). To protect the thermoelectric cooler from overvoltage, a maximum voltage is specified at the VLIM pin. This voltage is supplied and set by the second 12-bit DAC (typical range 0-to-1.5 V) or by a simple resistance-divider network. The VTEC pin is connected to one of the eight ADC channels, allowing the actual voltage across the TEC to be monitored. The TEMPOUT pin is connected to the second ADC channel, allowing the TEC temperature to be dynamically monitored (typical range 0-3 V). An op amp (OP184, OP162, etc.) is used ahead of each of the ADC inputs for signal scaling, buffering and filtering, if needed. Two digital inputs are used: TEMPLOCK indicates that the desired TEC temperature has been reached; THERMFAULT is used to

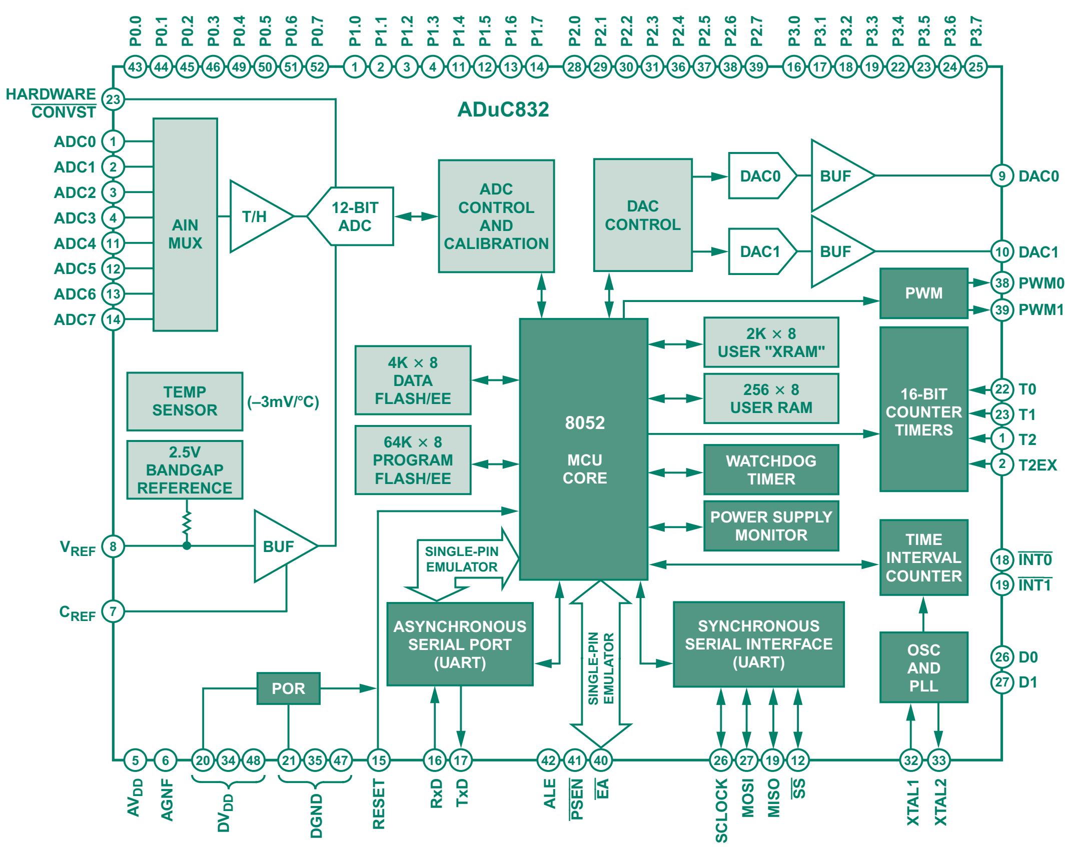

Figure 2. MicroConverter block diagram.

indicate a thermistor malfunction. One digital output is connected to the SD pin, allowing the device to be put into a low-current shutdown mode.

Laser Diode Driver

As part of the system, a laser-diode driver (LDD), the ADN2841, is used to control both average power and extinction ratio of the laser diode using a dual-loop control scheme. The extinction ratio is controlled as a function of modulation current, while the average power is controlled by the bias current. This dual loop configuration compensates for the variation in laser diode slope efficiency due to temperature, aging and diode-to-diode production tolerances, and enhances the designer's ability to source laser diodes from multiple manufacturers.

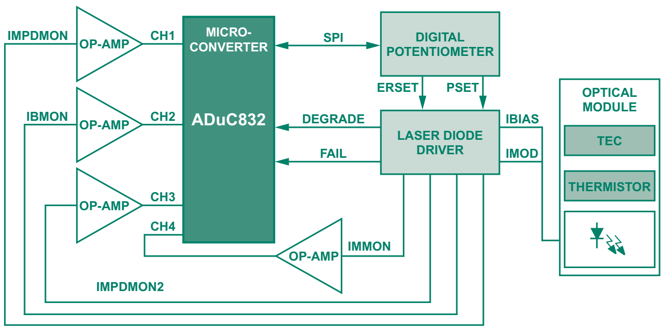

Figure 4. The MicroConverter sets the average power and extinction ratio of the laser diode, and monitors alarms.

The MicroConverter is used for both control and monitoring. Figure 4 shows that the extinction ratio (at the ERSET pin) and the average power (at the PSET pin) are set using an ADN2850 dual 10-bit digital pot. This pot is controlled through the *serial peripheral interface* (SPI) port. The monitor photodiode currents, IMPDMON and IMPDMON2, flow to ground through 1.5-kΩ resistors to provide voltages proportional to the monitor currents. The diode's modulation and bias currents, IMMON and IBMON, flow to ground in the same way. The voltages developed across these resistors are connected to the ADC channels, making them available in a digital format. The ADN2841 has active high monitoring alarms to identify degraded-diode and failed diode conditions. These two digital outputs are connected to two general-purpose I/O pins.

APD Monitoring and Biasing

Avalanche photodiodes are known for their extreme sensitivity and high internal gain. These characteristics make them ideal for optical receiver applications that require optimum sensitivity. Unfortunately, such high gains necessitate bias voltages ranging from 40 to 60 volts. The designer must also deal with the fact that the APD gain function is temperature dependent. The gain can be held constant by adjusting the APD bias voltage as the temperature changes. Figure 5 shows how an ideal solution to this problem can be implemented with a DAC, a switching regulator, and an adjustable voltage booster circuit.

The gain can be held constant by increasing the APD bias voltage as the temperature increases, as specified by the APD manufacturer. This change is typically expressed in %/°C, and ranges from 0.15%/°C to 0.30%/°C.

The ADP3031 switching regulator can provide output voltages of up to 12 volts. Several ADP3031 boost stages can be cascaded to achieve the desired final voltage.

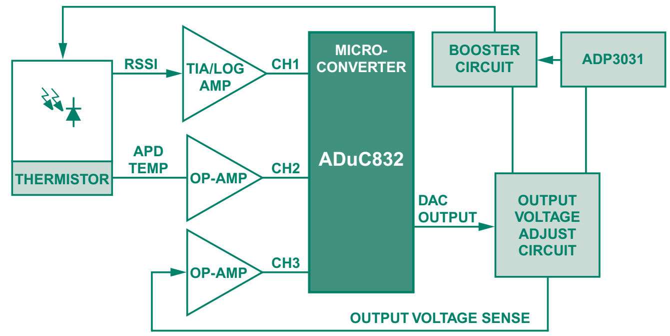

Figure 5. The ADuC832 controls the APD biasing and gain, and reads the received signal strength indicator.

A DAC is used in the range of 0-to-2 V to vary the voltage across the diode with temperature. The actual voltage across the diode can be monitored with the A/D, thus providing complete closed-loop control. With the diode gain maintained at its target, the received optical signal strength can then be accurately monitored with a transimpedance amplifier (TIA) or a log amp plus another channel of the ADC. Calibration coefficients can be conveniently stored in Flash data memory, enabling adjustments to be made as needed.

The 16-Bit Interface

This interface is accomplished using general-purpose I/O ports 0 and 2, plus an external latch. It serves two main functions: as a memory interface for the ADC when it is run in direct memory access (DMA) mode; and as a general-purpose 16-bit peripheral interface through the use of a dual-port RAM or other type of memory. Figure 6 shows the details of such a configuration.

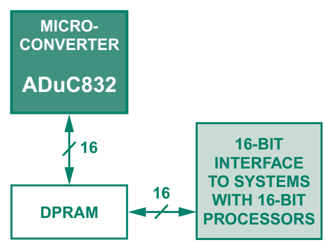

Figure 6. The MicroConverter and its 16-bit interface for data exchange.

The ADC runs at a maximum update rate of one conversion per 5 µs. At this rate, the microcontroller has 5 µs to read the ADC result and store it in memory for further processing. It has to be done within this time interval or the next sample will be lost—especially time-consuming when using an interrupt routine for the ADC. Thus, in applications where the MicroConverter cannot service a very fast interrupt rate, DMA mode should be used. In DMA mode, ADC results are written directly to external memory.

Like any standard 8051-compatible controller, this 16-bit interface can be used to exchange data with systems running a 16-bit processor. The dual port memory helps prevent bus altercation and contention—and provides a somewhat independent interface system. Because "real estate" (circuit-board area) is critical in most optical modules, integration of ADCs, DACs, Flash memory, and an 8052 MCU in a 56-lead CSP package provides the designer with a compact and powerful solution for optical communication systems.