Brett Novak
Marketing Manager
C2000™ microcontrollers
Texas Instruments, Houston

Utilizing microcontroller integrated analog comparators to provide power protection and reduce board space

Introduction

Today, increasingly more designers are turning to digital microcontrollers for the control of their power stages in both motor control and digital power systems. Utilizing the integrated analog comparator functions of microcontrollers, such as the C2000™ Piccolo™ microcontrollers from Texas Instruments, provide system power protection while also allowing designers to reduce the number of external analog components required at the board level.

In these motor control and digital power systems, designers are still limited to the analog domain for preventing over or under voltage situations in the potential event of an execution error in the microcontroller itself. By utilizing the integrated analog functions the C2000 Piccolo microcontroller series from TI, systems can be designed around a single controller eliminating the need for this external support circuitry, primarily concerning the use of analog comparators for monitoring over or under voltage and current events in the analog domain of the power stage.

The Piccolo microcontroller advantage

Leveraging TI's high-performance TMS320C28x™ core, Piccolo microcontrollers provide all of the necessary performance and peripherals needed to control a system with a single stand-alone controller. With its ample headroom and specialized peripherals, Piccolo microcontrollers enable developers to implement more advanced control algorithms to further improve performance while lowering system cost.

The Piccolo microcontroller architecture has been optimized for digital control applications with advanced architectural features to enhance high-speed signal processing. Piccolo's main CPU core has built-in digital signal processing (DSP) capabilities, such as a single cycle $32{\times}32$-bit multiply and accumulate unit, which greatly speeds computations. Furthermore, the control peripherals, such as the analog-to-digital converter (ADC) and pulse-width modulators (PWMs), are designed to be very flexible and easily adapt to almost any use, requiring very little software overhead. For example, the ADC has an auto-sequencer which developers can program to cycle through samples in a specific order so that values are ready when the application needs them. With more intelligent control peripherals and a powerful CPU core, control loops run tighter, both improving the dynamic nature of control algorithms and resulting in better disturbance behavior.

Important Piccolo MCU features include:

- 40 to 90 MIPS of processing performance
- Single 3.3-V supply for full operation
- Dual-internal, high-precision oscillators; no external crystal necessary
- 12-bit ADC with 16 channels and a maximum sampling frequency of 4.6 mega-samples per second
- Up to 19 channels of PWM output with configurable automatic dead band
- Up to 8 of the 19 PWM channels can operate in high-resolution mode with a resolution as low as 150 picoseconds
- Integrated analog comparators tied directly between dedicated inputs and PWM outputs (as well as dedicated output channels) eliminating the need for external analog components

Piccolo MCUs Integrated Analog Comparators

TI's Piccolo microcontroller series offer two to three analog comparators, depending on the device series. For this article, we will focus on the F2802x Piccolo microcontroller series, which features two comparators. Although they are integrated into a digital device, these analog comparators behave like traditional 30nS analog comparators they are. These comparators are asynchronous to the internal clock of the F2802/3x/6x microcontrollers – as long as the device itself has power, the comparator block will function appropriately. These comparators have two inputs – similar to a standard analog comparator but tied to device pins through the analog input/output (AIO) mux – and also have the added ability to be internally referenced to a voltage by utilizing the internal digital-to-analog converter (DAC) on the device. This internal DAC function is important in applications, such as peak current mode control, for digital power stages, because this DAC can act as a ramp generator for the peak current mode trip point. The output of the comparator block can also be utilized internally to the device by tying to the PWM trip zone, or again through the GPIO mux, can be referenced externally. This white paper focuses primarily on the F2802x series of devices, but the internal comparator function can be translated to the F2803x and F2806x Piccolo series, as well.

Utilizing the Comparators Externally to the F2802x Piccolo Microcontrollers

Because they are implemented as true analog components, the comparators inside the Piccolo F2802x microcontrollers can be utilized to control functions external to the processor. Referring to Figure 1 below, one can simply tie the output of the comparator to an external device pin through changes in the General Purpose Input/Output (GPIO) mux. Rather than having the comparator trigger an internal PWM event, such as when used in Peak Current Mode Control, we can have the comparator output an active high or low signal external to the device through the GPIO mux. The analog input trip-point characteristics can either be internally or externally referenced with a maximum input of 3.3 volts.
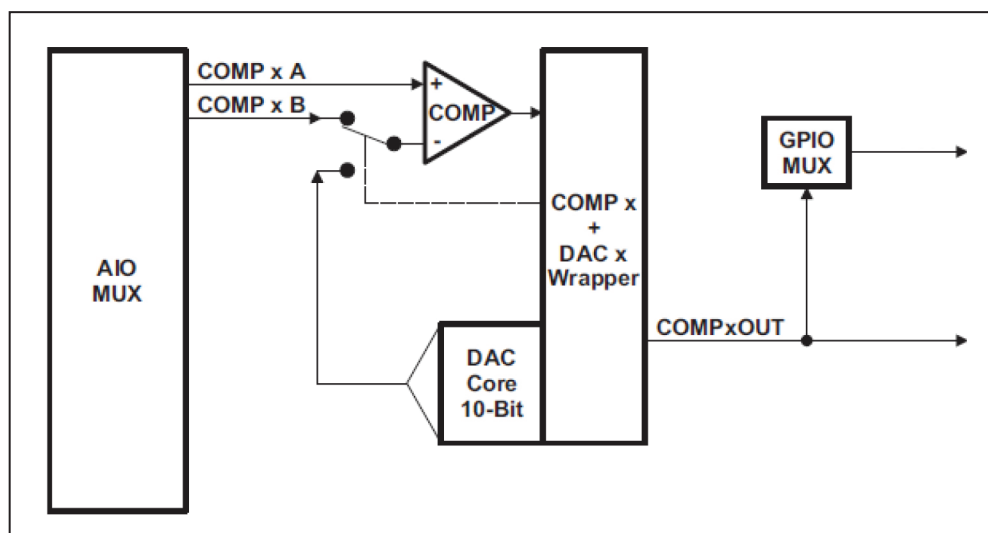

Figure 1. Comparator output through changes in the GPIO mux.

One such use case for this would be the reduction of board-level components when utilizing the F2802x Piccolo microcontrollers as a "housekeeping" microcontroller in a system that utilizes an analog controller in the power stage. Much the same as when used in a digitally controlled system, the analog comparator function can be used to enable or disable the power stage when used in conjunction with power supply devices that have an enable or disable pin. Many times, analog comparators are also used to trip relays within the system, or start a particular processor task. Rather than implementing these functions with external devices, we can now integrate these functions into the micro-controller itself, saving both board real estate as well as cost.

Now that we have touched the structure and setup of the internal analog comparators of the Piccolo F2802x microcontroller series, we can now focus on using these comparators in a development environment on TI's C2000 LaunchPad evaluation kit.

The C2000 LaunchPad is a low cost evaluation kit featuring the F28027 Piccolo microcontroller. The C2000 LaunchPad features pin headers that allow a designer to test various analog and digital inputs and outputs of the C2000 microcontrollers. This kit also includes an isolated USB to JTAG interface, eliminating the need for expensive, external emulator hardware while at the same time providing protection for the development PC. For the software setup of this example, we will demonstrate the VisSim graphical, model-based embedded software tool, provided by Visual Solutions, Inc. A two month free trial version of VisSim can be downloaded directly from their website at www.vissim.com.

Test Case – Externally referenced comparator event triggering PWM events
In this test case using the C2000 LaunchPad (Figure 2), we have a very simple VisSim diagram that generates a 25Khz PWM signal driving GPIO0 and GPIO1, with an externally referenced comparator signal that triggers a pair of corresponding high and low PWM events and a GPIO trip. The example below is a screenshot of the VisSim diagram with plots showing comparator output levels in blue and green, and the voltage applied to the input A comparator pins in yellow. In the VisSim diagram, the input voltage has been normalized to represent VDDA as 1. VDDA is set to 3.3 on the C2000 LaunchPad. As can be seen on the plots, we are cycling the input signal between 0 and 3.3 V.

In the VisSim diagram, comparator-1 DAC is set to .1 full scale (.33V) and comparator-2 DAC is set to .9 full scale (2.97V). The DAC values are plotted in red in the same subplot as the input voltage to make it easy to see when comparator trips should occur. Additionally, we have configured comparator-1 to turn the PWMs full on if the input voltage falls below the DAC value of .33V. Comparator-2 is configured to turn the PWMs full off when the input voltage exceeds 2.97V and trip GPIO-3 to be tripped (the hardware also allows the PWMs to be put in HiZ mode on a comparator event). When the diagram is run, the LEDs on the C2000 LaunchPad will be at a medium brightness if the supplied voltage is within the comparator bounds, or no voltage is applied to either ADCIN2 or ADCIN4. Thus when the input voltage falls below .33V the LEDs turn off and above 2.97V, they turn on to full brightness. Since we also want to demonstrate using the comparator inputs and outputs, the output of COMP2DAC is also tied to GPIO3. This would be indicative of the use when triggering an event external to the F28027 Piccolo microcontroller, such as shutting down an external power stage, but now when we tie ADCINA4 to 3.3V, two of the LEDs on the far right light to full brightness, while the LED on GPIO3 at the far left turns off. This is indicative of the comparator triggering GPIO3 high. We can also use an oscilloscope on pin J1-5, and when we connect and disconnect 3.3V to pin J1-6, we will see a logic level shift.

If a variable voltage supply is not available, you can tie a jumper between the GND pin and ADCIN2 (Jumper from J5-2 to J1-8,) the PWM will trip low, and turn the LEDs off. If we disconnect this jumper, the LEDs return to medium level. We can then tie 3.3V to ADCIN2 (jumper from J1-1 to J1-6,) tripping the high-threshold of the comparator, and the LED's will light up to full brightness while the LED on GPIO-3 turns off. Removing this jumper again returns the LEDs to a medium level, and illuminate the LED on GPIO-3 on the far left of the C2000 LaunchPad.
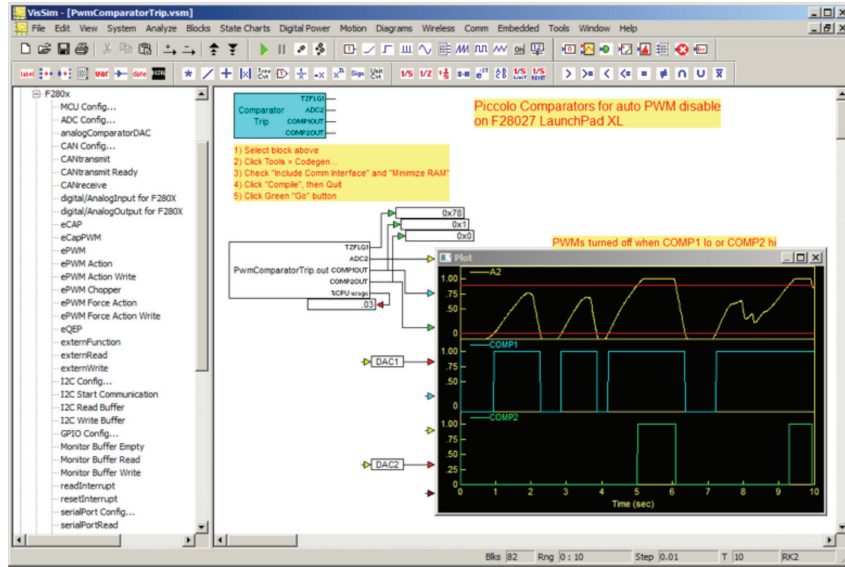
Figure 2. VisSim Diagram of two comparator triggered events affecting the PWM outputs of the C2000 microcontroller.

The following diagram below (Figure 3) is the VisSim diagram that actually runs on the C2000 LaunchPad hardware. We are initializing the comparator DACs for the threshold levels using fixed point constants of .1 for comparator-1 and .9 for comparator-2. (corresponding to 0.1@Fx6,16 corresponding to 0.33 and 0.9@ Fx6,16 corresponding to 2.97 volts.) The C2000 LaunchPad will support ADC inputs between GND and 3.3V. Notice that in this example, we are able to setup the entire structure of the PWM units, the ADC inputs, the comparators and the corresponding GPIO output events without writing any code.
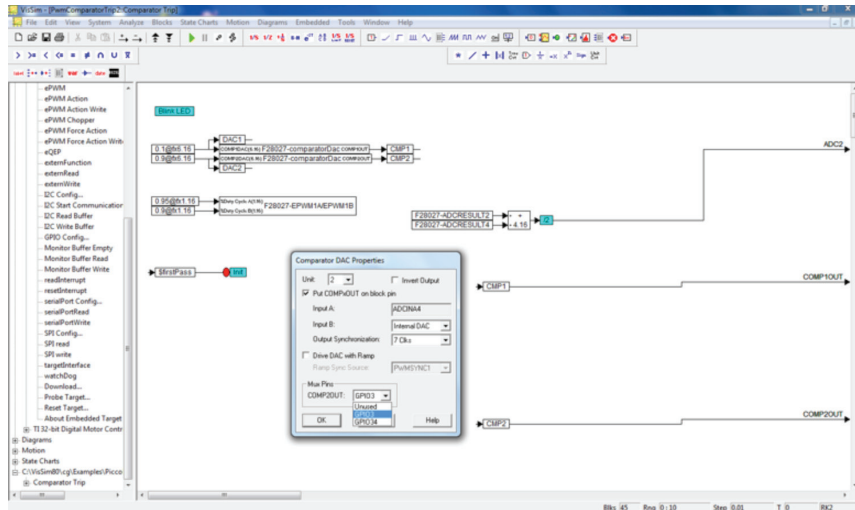

Figure 3. The VisSim diagram running on the C2000 LaunchPad hardware

This example for testing the comparator functions on the C2000 LaunchPad are available in VisSim by going to Embedded->Examples->Piccolo->Launchpad-> and choosing either PWMComparatorTRIP2.

In Conclusion

In this paper we have looked at the potential for using the analog comparator functions of the Piccolo microcontroller unit as a way to increase system functionality while decreasing the necessity for external components, with the potential to save both cost and board space. We have also explored the setup and demonstration of these functions using the low-cost C2000 LaunchPad platform along with the completely graphical programming solution VisSim.

For More Information

For more applications, hardware and software examples please refer to TI's controlSUITE™ software. This downloadable GUI features C2000 based development tools, application notes, design guides, hardware schematics and software examples, including the digital power and motor control libraries compatible with the F2802x Piccolo series of microcontrollers.   Download it here: **www.ti.com/controlsuite**.

For more information and a free trial download of the VisSim simulation, modeling and programming software from Visual Solutions, Inc., please visit their website at **www.vissim.com**.

For more information on peak current mode control utilizing the internal comparators and slope compensation DAC, please refer to these technical application notes:

Step-by-Step Design Guide for Digital Peak Current Mode Control: A Single-Chip Solution
Dr. Ali Shirsavar

Digital Peak Current Mode Control With Slope Compensation Using the TMS320F2803x
Dr. Ali Shirsavar and Richard Poley

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