# CLOZD$^{TM}$ LOOP TECHNOLOGY ADVANCES DIGITAL POWER CONTROL

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**Abstract**

Flexibility and simplicity have been key to success in digital power control based on ten years experience in this emerging field. A controller has been developed to satisfy a wide range of tasks quickly and easily, including common power conversion and challenging process controls. A single product that may be reconfigured for multiple tasks saves development time and component costs while increasing reliability. Lessons learned are shared through the evolution of this product to benefit other developers in digital power control.

## Flexibility Inspires Product Evolution

Designers often spend excessive time on custom applications because dedicated analog chips are too specific and programmable digital parts are too general. A practical solution is to add flexible interfaces to a closed loop controller for quick customization of digital power converters. The patented flexible controller (Ref. 11) in Figure 1 has dedicated features that can be quickly configured to satisfy a wide variety of tasks without programming. Utilizing the same component in multiple applications allows savings on parts by purchasing in volume, reduced development time by reapplying familiar technology, and increased reliability by using proven components.

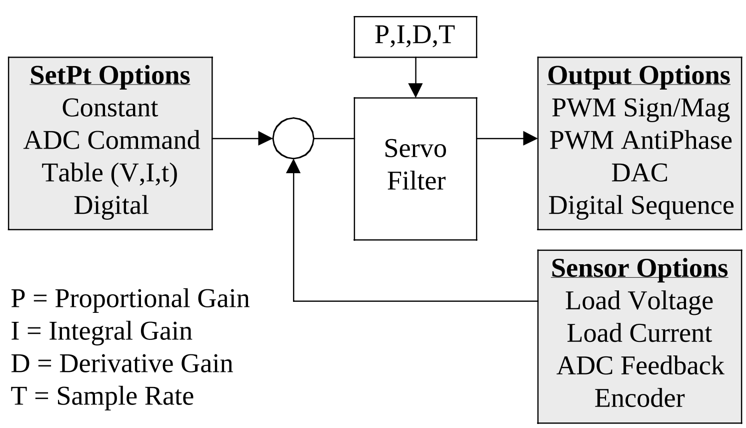



**Figure 1. Introduction of Patented Flexible Controller in 1998 Quickly Configured for Multiple Applications without Programming (Ref. 1: PSW 1998)**

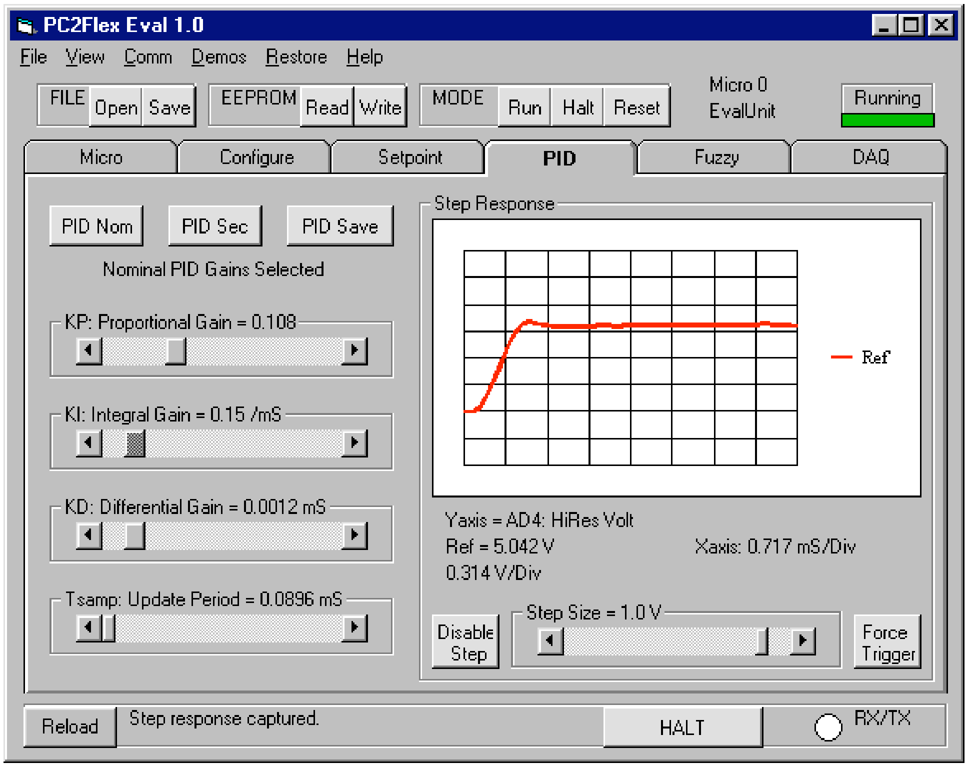



**Figure 2. Serial PC Interface for First Flexible Digital Power Converter that Eased Customization but PID Control Performance was Marginal (Ref. 2: PSW 1999)**

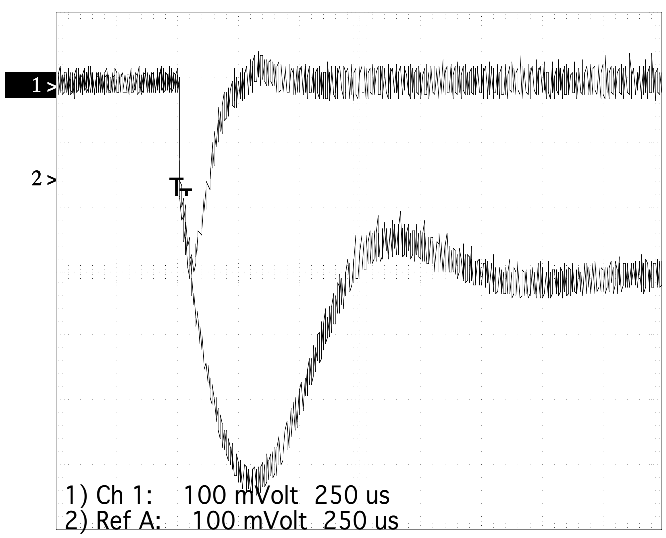



**Figure 3. PID Performance Enhanced in 20MHz 8-Bit Micro with Slow ADC and no HW Multiplier through Understanding of Digital Power Control (Ref. 3: EDN 2005)**

Trace 1: PID Closed Loop Response to 3A Step Load (100mV/Ydiv, 250uS/Xdiv)

Trace 2: Open Loop Buck Converter Response to 3A Step (100mV/Ydiv, 250uS/Xdiv)

The serial PC interface in Figure 2 allowed full customization with point and click ease, but the 1mS PID control performance was weak due to the limited capabilities of the 20MHz 8-Bit PIC with slow ADC and no hardware multiplier. The PID performance improved to the 250uS response in Figure 3 for the same microcontroller based on greater understanding of digital power control over time, but the system still lacked practicality.

Customers purchased digital power evaluation kits as curiosity boomed (Ref. 9 & 10), but long-term sales were sluggish due to the narrow market niche. Novices requested excessive support for a low cost product to be profitable, and experts preferred to design their own systems. Additionally, the burden of loading and navigating software on a PC for basic operation was excessive for most applications. When it comes to work, people are more interested in simple technology that quickly satisfies needs rather than sophisticated technology that looks impressive.

## Simplification through CLOZD™ Loop Control

CLOZD™ (Caldwell Loop Optimization in Z-Domain) is a digital closed-loop control chip developed for simplicity, robustness, and flexibility. Select the desired control configuration in Figure 4 through pin settings and quickly close a loop around a power supply, motor drive, lamp, heater, fan, valve, actuator, transmitter, transformer, regulator or virtually anything that needs to be controlled. Closed loop control may be the most common and yet the most challenging task in electronics. By automating this task with flexible interfaces that are easy to use, a wide range of custom applications are quickly satisfied.

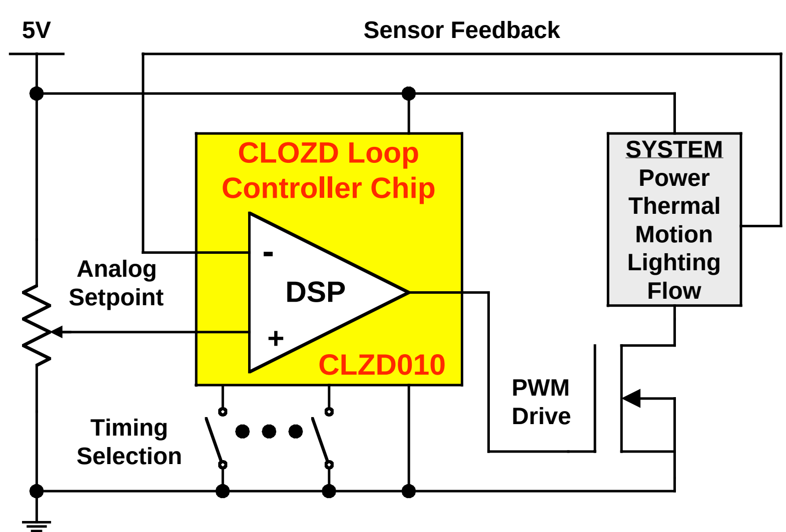



**Figure 4. CLOZD™ Loop Controller Configured by Single Time-Domain Parameter that Eliminates Complex PID and Burdensome PC (Ref. 4: N&V 2004)**

The CLOZD™ algorithm compares the sensor feedback to the analog setpoint and calculates the appropriate PWM drive to equalize the two. Figure 5 shows the heater voltage and temperature response for a thermal system, both open and closed loop. Simply inspect the open loop time constant of the system (approximately 180 seconds to reach 63% of final value) and look up pin setting from the data sheet. Timing is adjusted for a specific application through a single parameter, in comparison to the three parameters of the analog-based PID technique. Another simplification is that the control adjustment is an intuitive time-domain setting rather than the complex PID frequency-domain settings.

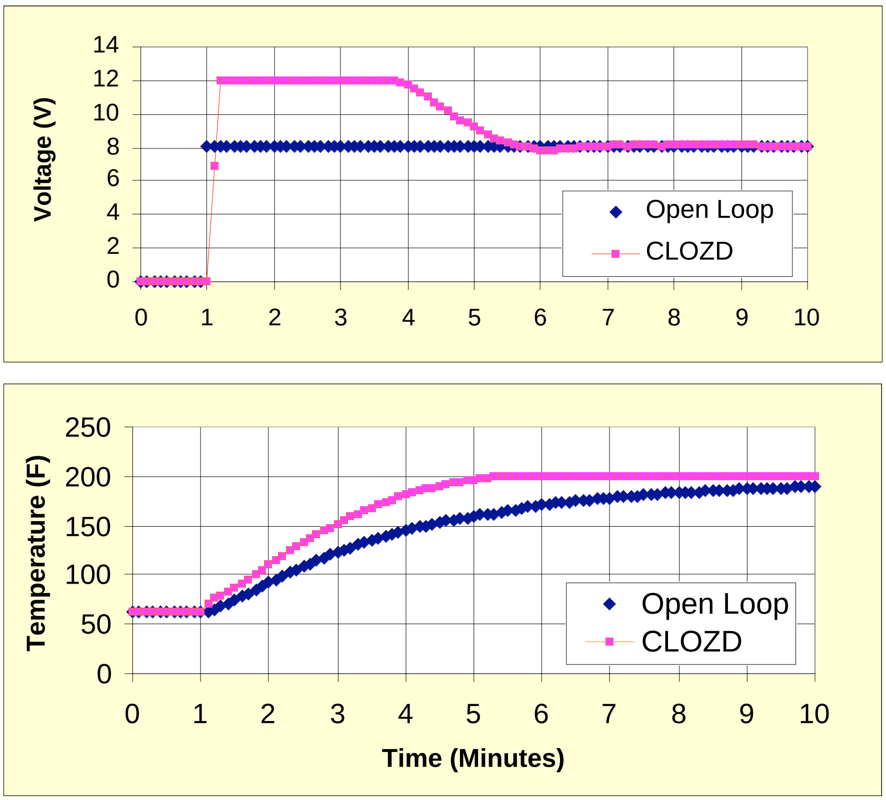



**Figure 5. CLOZD™ Configuration by Intuitive Time-Domain Setting through Inspection of Open Loop Response in Thermal Example (Ref. 5: Flextek 2004)**
(Open loop thermal response takes about three minutes to reach about two-thirds of its final value so CLOZD™ timing set slightly faster at 134Sec.)

The triac circuit in Figure 6 is small and inexpensive because load and housekeeping power are derived directly from line voltage. Constant light intensity is maintained by the CLZD010 closed-loop controller that automatically adjusts timing of triac Q1 firing until Feedback signal and setpoint Vset command are equal.

The 5V supply is a charge pump that energizes C1 on the negative swing of line voltage, and then transfers charge to C2 on the positive swing. Triac Q1 is a latching switch that conducts in either direction until gate drive is removed and load current drops below its holding threshold, which occurs at zero crossing of line voltage detected by R3. The triac gate is pulsed for 100uS to turn on the load for the remainder of each 60Hz half-cycle, so higher power is achieved by turning on earlier in the half-cycle.

The lighting circuit can be quickly modified for thermal control. Closed-loop timing is changed from 262mS to 134Sec for optimal temperature response with controller pins CS3-CS0. The heater is intitially driven at high power levels until the temperature nears its final value, then power is reduced to avoid overshoot. Pins P2-PS0 set PWM output mode and frequency, which is configured for 60Hz triac switching in this case.

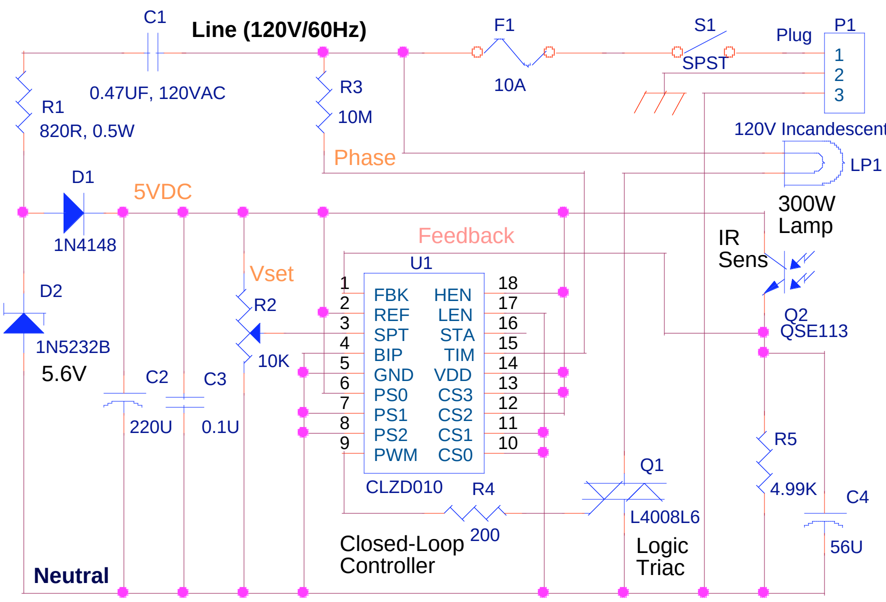


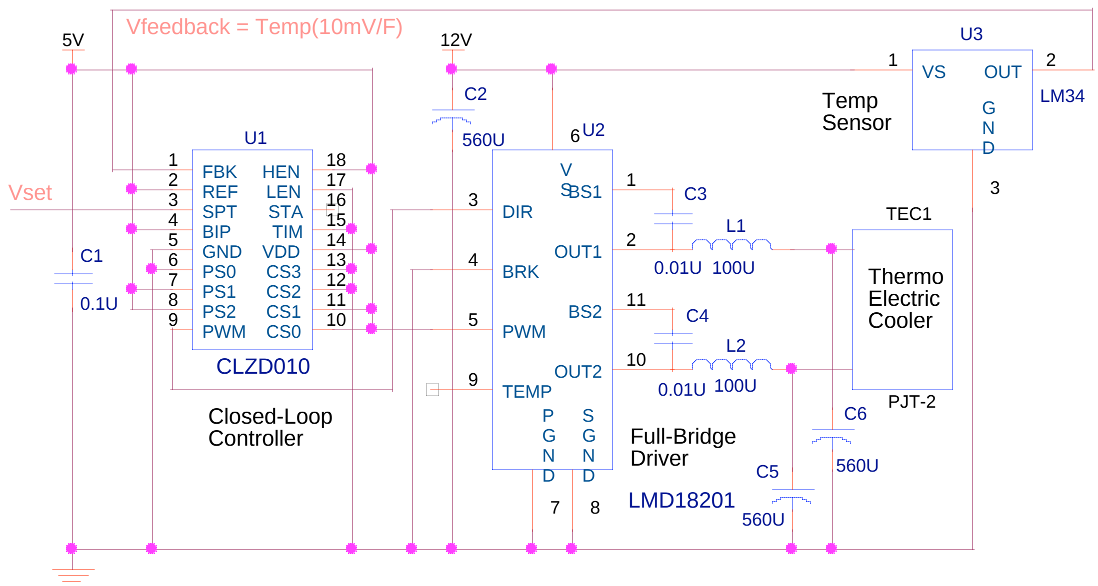

**Figure 6. Complete Schematic for CLOZD™ Chip Configured to Drive Triac for Low Cost Lighting Controller with 262mS ($\tau$ = 4.99KΩ • 56µF = 279mS) Timing that is Easily Changed to Heater Circuit with 134Sec Timing (Ref. 6: EDN 2004)**

The LMD18201 motor driver is advertised as a 3A full-bridge, but scrutiny of the data sheet reveals that it can also be applied as a 6A half-bridge by reconfiguring logic pins and paralleling outputs. Adding the CLZD010 closed-loop chip results in a flexible power amplifier and process controller.

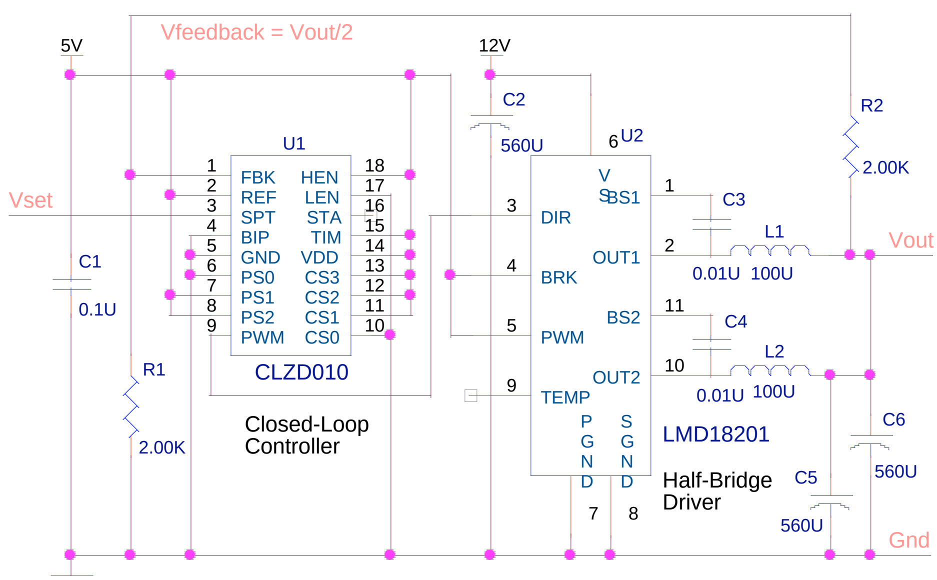
Figure 7A illustrates a thermal controller that uses a Thermo-Electric-Cooler (TEC) or Peltier Cell to heat (PWM>50%) or cool (PWM<50%) depending on current direction. This circuit is useful for applications requiring variable temperatures that include ambient. The BRK pin of the driver is tied low for anti-phase full-bridge switching. The controller is configured for a 134Sec closed-loop time constant with its BIP pin tied high to start the PWM at 50% for zero initial power transfer (both outputs equal).

Figure 7B illustrates a power amplifier that sources or sinks current while maintaining constant voltage Vout at twice the analog setpoint Vset. This circuit is a switching converter that behaves like a low-frequency (100Hz) high-power (10V/6A) op-amp. It requires few parts that are inherently robust because critical functions are integrated, including digital signal processing, power switching, and fault protection.

The PWM output of CLZD010 is connected to the DIR input of LMD18201 while the BRK and PWM pins of the driver are tied high for half-bridge operation in Figure 7B. The controller PS2-PS0 pins are set for 31.25KHz PWM switching and CS3-CS0 pins are configured for 128uS control updates. The controller automatically adjusts the duty cycle of the driver until the feedback voltage equals the setpoint command.




A. Bidirectional TEC Thermal Controller with 134 Second CLOZD™ Timing

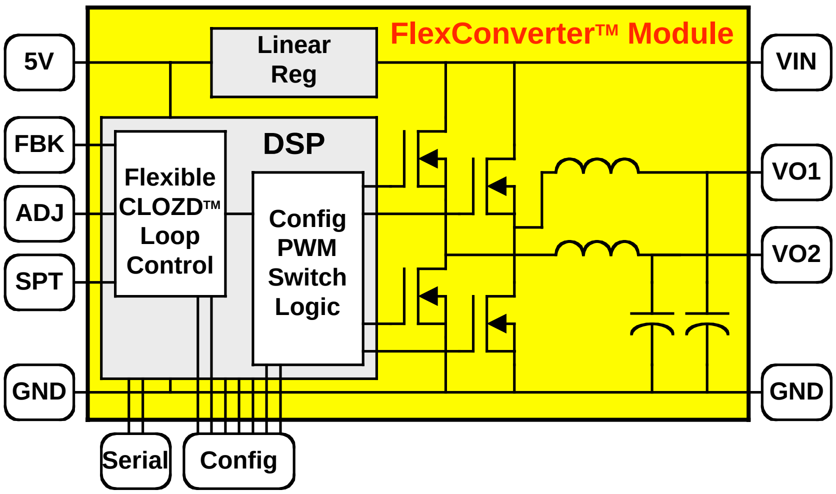



B. Power Amplifier with Paralleled Outputs and 128uS CLOZD™ Timing

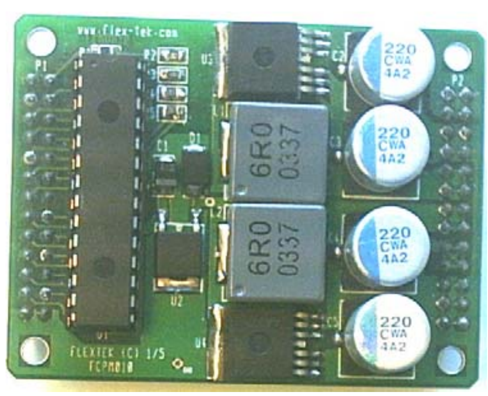
**Figure 7. Flexible Power Amplifier and Process Controller with CLOZD™ Chip and Full-Bridge Driver (Ref 7: Electronic Design 2004)**

## FlexConverter™ Optimizes Flexibility and Simplicity

Figure 8 contains a block diagram and photo of the FlexConverter™ module. The power stage has dual filtered half-bridges that can be run independently or paralleled for higher current and lower ripple, as well as full-bridge or sequentially switched. The power module is 2.5in X 1.9in with 0.1in spaced pins to fit standard prototype boards or solder to PCB for production. Input voltage range is 10–14V and output is 0–12V. Total output current is 10A through the two phase shifted outputs. Full load efficiency is 92% and recovery time to stepped loads is less than 100uS.

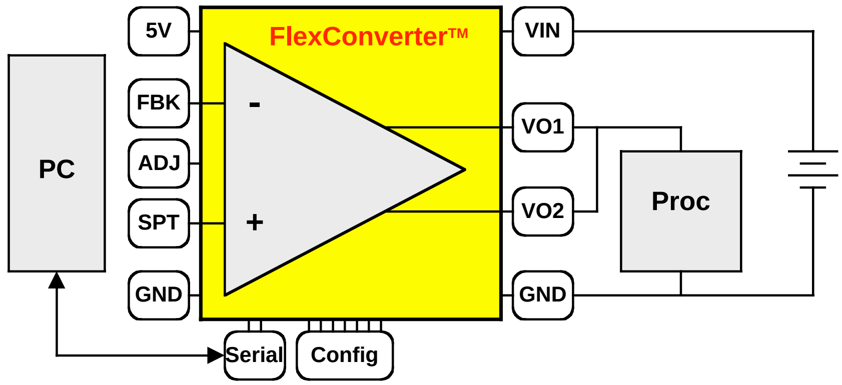



A. Module Block Diagram

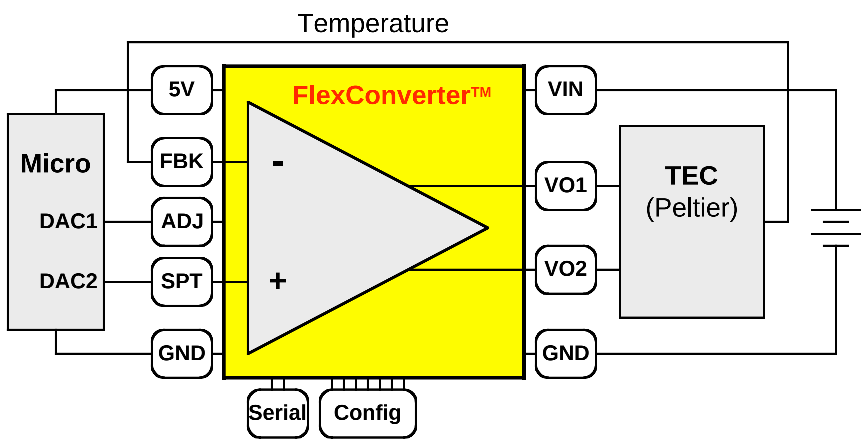


B. Module Photo (2.5in. x 1.9in.)

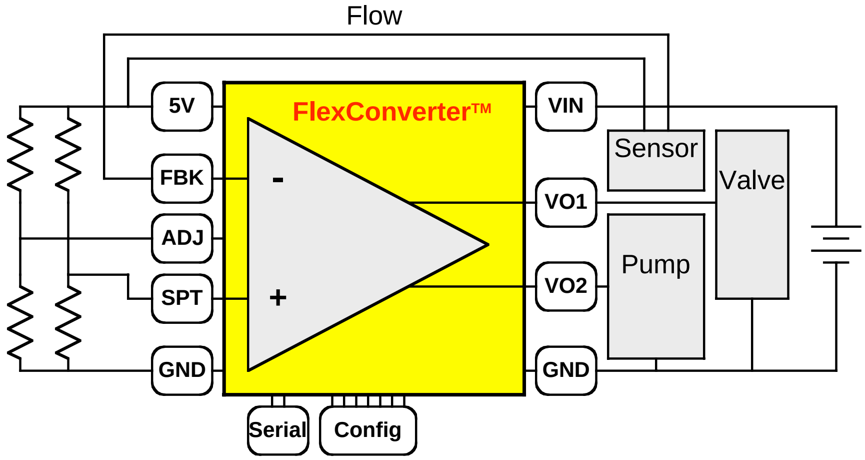
**Figure 8. FlexConverter™ combines Simple CLOZD™ Loop Controller with Flexible Power Converter (Ref 8: PSW 2005)**




A. PC-Based Point-Of-Load Converter with Paralleled Outputs




B. Bi-directional Thermo-Electric-Cooler with Full-Bridge Power Stage




C. Automatic Flow Controller with Sequential Drives

**Figure 9. Example FlexConverter™ Applications**

On-board intelligence is accomplished through an embedded DSP preprogrammed as a flexible CLOZD™ loop controller. This patented (others pending) product may be quickly applied as a digital power supply, TEC thermal regulator, DC motor driver, or controller for lighting and flow applications. Configuration is through pin settings for stand-alone operation, while an optional serial port enables processor or PC communication.

Figure 9 illustrates a few of the countless FlexConverter™ applications. Circuit A is a PC-based POL converter with parallel phased outputs to increase current and reduce ripple. By grounding the appropriate configuration pins, the outputs are applied full-bridge in circuit B for bi-directional thermal control (cooling or heating). The last example utilizes sequential drive where the valve is first gradually opened then the pump is linearly powered to maintain constant flow. Alternately, the two converter outputs could be set independently as a dual power supply.

A configurable power stage with adjustable controller is quick and easy to apply, and inexpensive because components are common and support is minimal. Design-from-scratch solutions reduce component cost but require extensive development efforts. Digital power converters are emerging but lack essential features for control applications. Programmable real-time controllers are useful but steep learning curves and significant software cycles drive up total costs.

## Lessons Learned

Consider that the most popular electronic components in history have been the voltage regulator, op-amp, and microcontroller because most projects require power, control, and customization. A system containing these components usually requires significant time and expertise to design and apply. However, combining the best features of these components into a single product simplifies the entire design process.

1) Simplicity and Balance
    a. Strive to satisfy rather than impress
    b. Best solution is simplest one that works
2) Convenient User Interfaces
    a. Shield users from operational complexity
    b. Serial port for advanced features only
3) Flexible Control Capabilities
    a. Digital control loop for recurring compensation changes
    b. Options enable innovation and standards limit progress

The first objective points out that digital power control should be applied to satisfy needs that are not easily accomplished through traditional approaches. Engineering rather than marketing should justify the burden of going digital (component cost, overhead power, and development time). The concept of simplicity is extended to the critical user interface in the second objective. If a customer has to provide a computer with special hardware and software drivers to simply adjust output voltage, then the advantage of going digital is questionable. While a serial interface can be useful, it should be reserved for advanced features, not basic configuration. Finally, most converters have control parameters set at the factory for a specific power stage and filter so a digital loop is not justified. Since the primary advantage of digital control is flexibility, manufacturers cannot assume they have considered every potential application. Provide customers with options that allow them to innovate, and standards will naturally evolve through product success.

FlexConverter™ fills the gap between digital power converters and programmable real-time controllers to satisfy a variety of power conversion and process control applications quickly and easily. Using the same product in a variety of applications reduces component cost through volume purchase, reduces development time by re-applying familiar technology, and increases reliability by utilizing proven components. Flexibility and simplicity are key to success in digital power control.

## References

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