Compensation Methods in Voltage Regulators

Feedback signals are used in voltage regulator circuits in order to produce a controlled output voltage. When properly implemented, feedback will improve the performance of the circuit. A major contributor to proper implementation of a feedback circuit is the compensation network. This article will give an overview of some methods used to implement compensation in voltage regulators including techniques for automatic digital compensation. **Bruce Rose, Technical Marketing Manager, CUI Inc, Tualatin, USA**

An analogy to assist in understanding compensation in voltage regulators lies in the suspension system of an automobile. Operators of cars desire different styles of rides depending upon the use of the car. Riders in limousines would like to enjoy a smooth ride and not notice any external disturbances. At the other extreme, race car drivers would like their cars to respond quickly to the external forces of starting, stopping and turning. While both of these styles of cars may experience similar disturbances, different reactions of the cars to the disturbances are desired. As a result, the suspension systems of the cars are tuned to react in the desired manner to specific disturbances. A properly tuned suspension system will give the car its desired ride qualities. Tuning the suspension of a car is similar to adjusting the feedback compensation circuit of a voltage regulator.

Switching regulators
In order to achieve good power conversion efficiency, design engineers often employ switching regulators (Figure 1). Typical switching regulators consist of two primary functional blocks; a power stage and a control stage. The power stage conducts the current flow in the voltage regulator. It contains switching FETs, a circuit to control the switching of the FETs and an output filter which includes inductance and capacitance.

The control stage provides the signals to the power stage such that the desired output voltage waveform is produced by the switching regulator. The control stage consists of an attenuator, an error amplifier, a gain circuit and a compensation circuit. The switching regulator can either be built with discrete components soldered directly to the host circuit board or obtained from manufacturers that offer voltage regulator Point of Load (POL) modules with the components placed on a daughter circuit board which is then connected to the host circuit board. Some advantages of POL modules are that much of the voltage regulator circuit design has been done by the module vendor and the modules can occupy less space on the host board than would a discrete solution.

Compensating analog voltage regulators
In most analog switching regulators, internal nodes are brought external to the circuit so that the user can select the circuit compensation components. This exte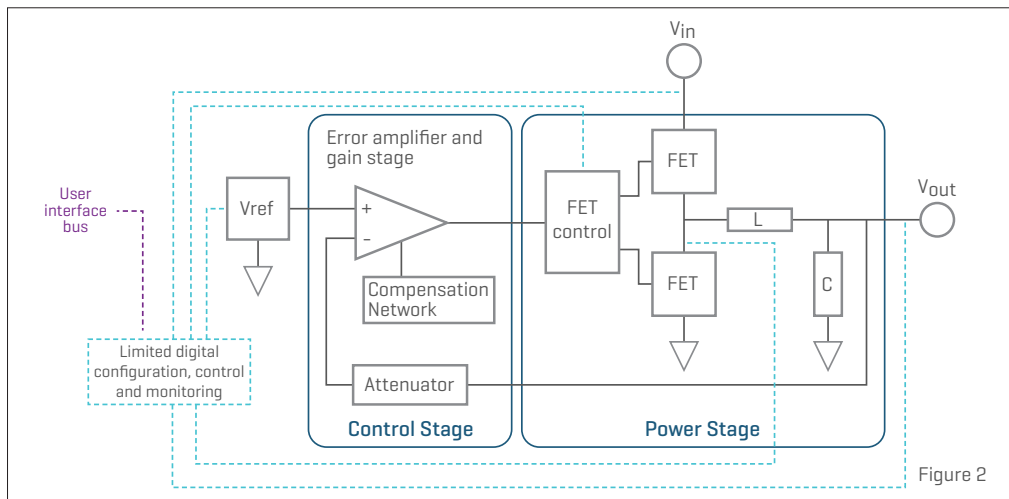rnal compensation feature allows the user to optimize the performance of the switching regulator for their application. Optimizing the voltage regulator transient response involves measuring or modeling the circuit and then calculating the values of the compensation components. The circuit is then modeled or measured with the compensation components installed. This process is often repeated many times until the desired result is achieved. Optimizing the compensation of a digital switching regulator is accomplished in a similar manner; however changes are made using firmware rather than physical components.

Proper implementation of the compensation network within an analog switching regulator requires engineers with special tools, skills and experience. If an analog switching regulator is measured during the compensation design phase, then the circuit board needs to be re-soldered many times. If the circuit is modeled and not measured, there is still the need to eventually solder together a physical circuit to measure the performance. The process of re-soldering the compensation components introduces a substantial level of risk to the design process. It is common that the wrong value of a compensation component is installed, another part of the circuit is accidently modified, or the circuit board is damaged during the design process. It is also possible that the circuits drawing power from the voltage regulator can become damaged due to improper compensation of the voltage regulator.

When any of these events occur, time delays and expenses are incurred to recognize the problem, identify a solution to the problem, and implement the repair. The above mentioned risks, procedures and required resources exist whether a discrete design of an analog switching regulator is implemented or a POL module
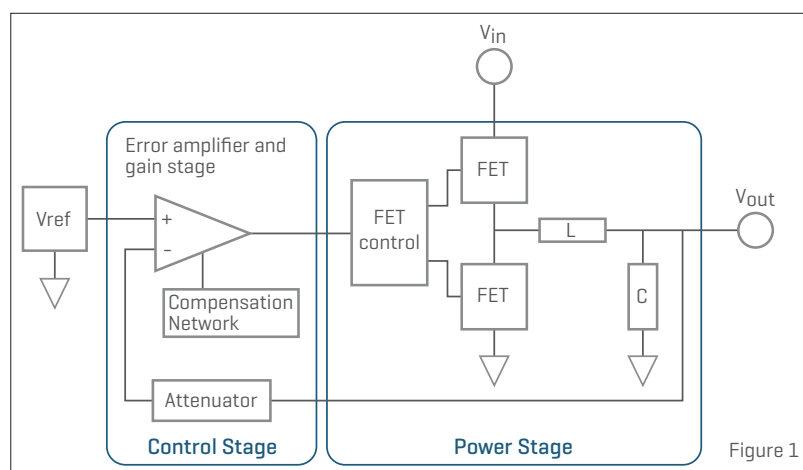
Figure 1

LEFT Figure 1: Analog switching voltage regulator

Figure 2

based upon an analog switching regulator is used.

One can think of the design of the analog switching regulator as a similar process to purchasing a kit car and then selecting and installing all of the suspension components. It takes specific tools, knowledge and experience to properly tune the suspension of a car. Adjusting the suspension in the car posses risks, including damaging the car while driving it with a poorly-tuned suspension, or breaking components while making suspension adjustments. In either case, time and resources will be required to repair the damage caused while tuning the suspension.

As a result of the increasing number of digital systems being implemented in today's designs, voltage regulator vendors are now offering analog switching regulators with 'digital wrappers' (Figure 2). The voltage regulator portions of these circuits are very similar to the traditional analog switching regulators. The digital wrapper enables the system to employ software to implement Configure, Control and Monitor (CCM) functions of the voltage regulator, in a limited manner. The ability to use CCM functions in a voltage regulator via software control is of benefit to the design team during the development phase and to the user of the final product.

Analog switching regulators with digital wrappers are being offered to design engineers for discrete designs and as POL modules. Some module vendors have chosen to include most of the compensation components internal to the module. The module user is then provided a single internal compensation node and is required to select only one resistor and one capacitor to adjust the performance of the module. The advantage of this process is that tuning the performance of the module is simpler than when the user must select all of the compensation

components. A trade-off of this compensation technique is that the user is not able to select the complete set of compensation network components.

The ability to select all of the compensation components would enable greater optimization of the performance of the voltage regulator. The ability to select only a single resistor and capacitor is similar to selecting the shock absorbers for a car, but not being allowed to tune any other component in the suspension system.

Compensating digital voltage regulators

The technical evolution of voltage regulators started with analog switching topologies for increased efficiency, transitioning to the addition of digital wrappers for limited CCM functions. Today digital switching voltage regulators are available to design engineers (Figure 3), providing superior performance to earlier topologies. Similar to analog switching regulators, digital regulators require a control circuit and a power stage. The power stage for a digital switching regulator is similar to that for an analog switching regulator. The control circuit in a digital

regulator is implemented with digital and mixed-signal circuits. An advantage of this topology is that extensive CCM functions can be implemented. The extensive set of CCM functions in a digital voltage regulator provides greater benefit than the limited CCM functions present in an analog switcher with a digital wrapper. Another advantage of digital switching regulators is that optimizing the performance of the circuit can be accomplished more easily and automatically.

The compensation function in a digital voltage regulator can be implemented as Proportional, Integral, Differential (PID) taps, which are coefficients used in the digital control circuit to define the response of the voltage regulator. An advantage of using firmware PID taps is that the designer can configure and control the performance of the voltage regulator with software. An infinite number of changes can be made to the response characteristics of the circuit without risk of damaging components or the circuit board. In addition, the behavior of the system can be monitored and the performance of the voltage regulator circuit can be re-tuned throughout the life of the product. This
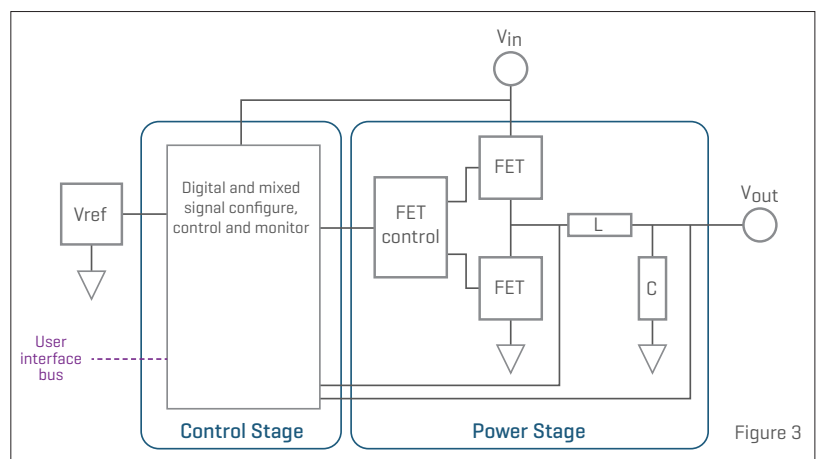
Figure 3

Figure 3: Digital switching voltage regulator

ability to easily modify the performance of the voltage regulator is similar to push-button suspension tuning which is available in some cars.

Auto compensation

Some advanced digital regulator controllers offer the ability to automatically compensate the regulator for optimum performance by monitoring the characteristics of the output voltage waveform. One advantage of automatic compensation is that the circuit designer does not need any special tools, knowledge or experience to optimize the performance of the voltage regulator.

In a regulator with analog compensation components, the compensation must be set such that the output voltage characteristics are acceptable over changes due to initial component tolerances, aging, temperature, input voltage and many other factors. This means that the circuit is never operating at the optimum performance point. Digital voltage regulators with automatic compensation enable the voltage regulator to operate at peak performance regardless of changes in the system. Automatic compensation of digital voltage regulators can be thought of as having an expert mechanic always in the car to optimize the ride without any burden on the driver or passengers.

CUI offers multiple families of commercially available digital voltage regulator modules with automatic compensation. Proper compensation of voltage regulators enables users to realize optimum performance from their circuits.

Tuning the performance of a circuit using traditional analog switching regulators involves a substantial level of risk. Vendors of some analog voltage regulator-based POL modules off er products that simplify the task of compensation by limiting the choices available to the user. Digital voltage regulators, on the other hand, enable firmware based CCM functions which permit the voltage regulator to operate at optimum performance.

All of these topologies require a design team with special tools, knowledge and experience in power supply design to create an acceptable solution. The multiple families of digital POL modules from CUI's Novum® Power line incorporate automatic compensation, allowing system designers ease of use and superior performance in next generation applications.

Digital Point-of-Load Modules Dynamically Set Optimum Stability
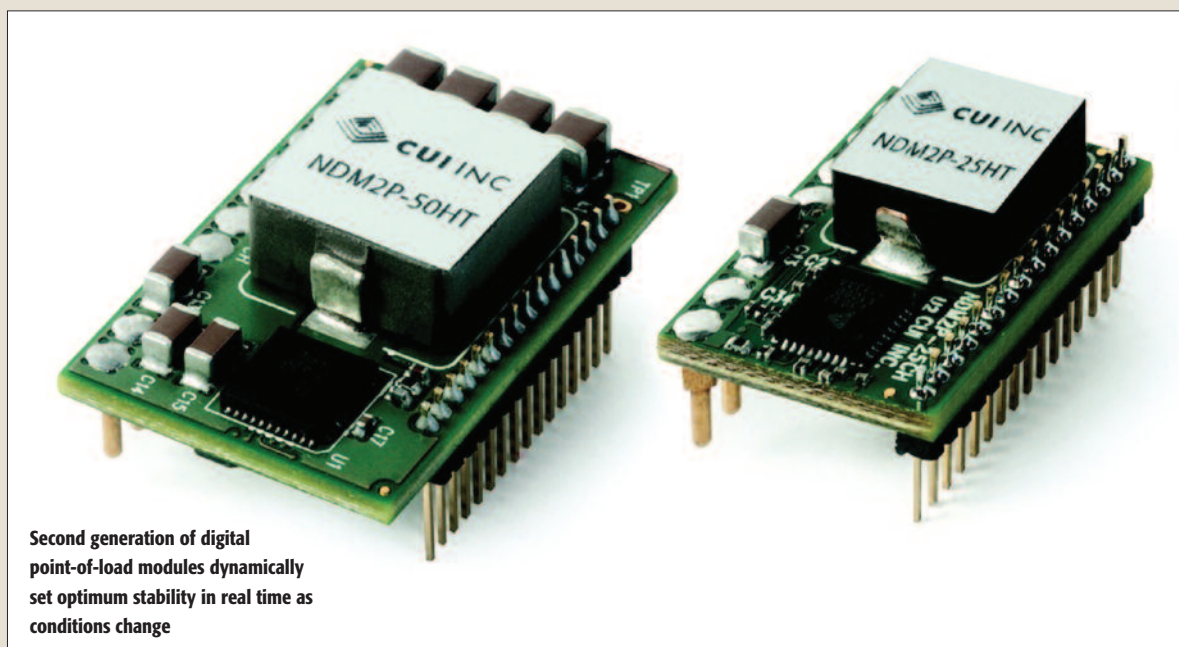
Second generation of digital point-of-load modules dynamically set optimum stability in real time as conditions change

CUI's new NDM2P offer true cycle-by-cycle compensation, autonomously balancing the trade-offs between dynamic performance and system stability. With the addition of these second generation modules based on Powervation's digital IC, CUI continues to offer a full portfolio of self compensating digital POL modules. With efficiencies above 93 % at half load, the NDM2P series is initially available in three compact DIP configurations; a 12 A, a 25 A and a 50 A. SMT and SIP versions will be available as well. Additionally, to support dual layout needs, the modules are footprint nested. The NDM2P series is available with an input range of 4.5~14 V DC and a programmable output range of 0.6~3.3 V DC. Features include active current sharing, voltage sequencing, voltage tracking, synchronization and phase spreading, programmable soft start and stop, as well as a host of monitoring capabilities. All features are dynamically programmable via PMBus commands or a simple GUI.