MULTIMODE VOLTAGE REGULATOR CIRCUIT

The present invention generally relates to voltage regulator circuits and particularly relates to a multimode voltage regulator having low-current and high-current modes.

BACKGROUND

Voltage regulators are used to convert a supply voltage from one value to a different value, frequently from a high voltage to a lower voltage. In some applications, voltage regulators are used to provide current to a load at a stable voltage, despite a varying supply voltage, such as from a battery. In other applications, a voltage regulator may be used primarily for converting an input supply voltage to an operating voltage that is more convenient or more efficient for a particular circuit. In some applications, both of these functions may be important. For example, the battery voltage in some mobile phones is nominally 3.6 volts, but varies considerably as the battery discharges. Some of the integrated circuits within the mobile phone are designed to operate at voltages as low as 1.0 volts, to minimize power consumption. These mobile phones typically include several voltage regulators to supply stable operating voltages for several distinct circuits operating at different voltages. These regulators are generally required to provide a constant output voltage regardless of whether the input voltage or the load current varies.

Two well known types of step-down regulators are the "linear" regulator and the switching regulator in the form of a "buck" regulator. Either of these types may be configured to provide a constant output voltage over a pre-determined range of input voltage variation and/or load current variation. A linear regulator includes an active pass device, such as a field-effect transistor or bipolar transistor, operated in its "linear," or "ohmic" region. Effectively, the pass device is controlled, using feedback from the regulator output, to act as a variable resistance, so that the output voltage is maintained at a desired level, regardless of variation in the load current or in the input supply voltage.

A buck regulator, on the other hand, relies on the energy storage capability of an inductor to convert an input supply voltage to a regulated output voltage. When a switching transistor is switched "on," current flows into an inductor connected between the input supply voltage and the load, and energy is stored in the inductor. When the switching transistor is turned off and a rectifying transistor between the inductor and ground is turned on, current continues to flow into the load as the inductor's magnetic field releases its energy. Feedback from the regulator output is used to adjust the on/off duty cycle of the two transistors, the on/off switching frequency, or both.

Those skilled in the art are aware that linear regulators are inherently inefficient at high load currents because of the resistive voltage drop across the pass device. The power dissipated in the pass device, and thus wasted, is linear with load current. However, the control circuitry for a linear regulator can be quite simple and can be designed to operate with very low power consumption. Thus, the absolute value of the wasted energy can approach zero as the load current requirements become very low. Buck regulators, on the other hand, can be much more efficient than linear regulators at high load currents, but tend to be inefficient at low load currents. The low-current efficiency of buck regulators (and switching regulators in general) is limited by losses in the switching and rectifier transistors, and because the control circuitry is more complex and consumes more power than that of a linear regulator.

In a modern mobile phone, the output current required to supply the phone's microprocessor circuits might vary from roughly 1 ampere when the phone is performing a processor-intensive task, such as processing high-quality graphics, to roughly 50 microamperes when the phone is in a "sleep" mode. In sleep mode, the mobile phone's processor may be doing nothing more than running a timer that periodically wakes the mobile phone to monitor a radio channel for incoming messages. Given such a wide range of load current, a linear regulator will be less efficient than a buck regulator when the regulator's output current is high, while a buck regulator will be less efficient than a linear regulator during the long periods when the phone is powered on but inactive. Since battery life of mobile phones and other portable devices is critically important to customers, improving that battery life is important to device designers.

SUMMARY

Combining a switching regulator, for use when a required load current is high, with a linear regulator, for use when the load current is low, results in higher efficiency for all load currents than can be achieved by either the switching regulator or linear regulator alone. The disclosed multimode voltage regulators may be especially attractive for use in devices such as mobile phones, in which long periods of very low current use are interspersed with periods of high current use. In certain embodiments, a switching regulator can be modified to form a multimode voltage regulator with only a few additional components.

In an exemplary embodiment, a multimode voltage regulator circuit includes a linear regulator sub-circuit configured to supply current to a load in a low-current mode, responsive to a first control signal from a first control path, as well as a switching regulator sub-circuit configured to supply current to the load in a high-current mode, responsive to a second control signal from a second control path. The circuit further comprises a shared error amplifier configured to generate an error signal based on the difference between a reference voltage and a feedback signal coupled from the load, and a switch configured to selectively route the error signal to the first control path in the low-current mode and to the second control path in the high-current mode.

In some embodiments, the multimode voltage regulator circuit is implemented as a monolithic integrated circuit, perhaps requiring an external inductor and/or external filter capacitor, while in others the regulator circuit is implemented with discrete devices or a combination of discrete devices and one or more integrated circuits. In some embodiments, the linear regulator sub-circuit and the switching regulator sub-circuit share a transistor, so that the shared transistor operates as a variable-resistance pass transistor in the low-current mode and as a low-on-resistance switching transistor in the high-current mode. Sharing components, such as the error amplifier and the shared transistor, between the low-current and high-current operating modes reduces the size and/or cost of the multimode regulator circuit.

Of course, the present invention is not limited to the above features and advantages. Those skilled in the art will recognize additional features and advantages upon reading the following detailed description, and upon viewing the accompanying drawings.