Linear or LDO Regulators & Step-Down Switching Regulators

Step-down voltage regulators used in electronic devices can be categorized into two separate classes: linear regulators and switching or DC-DC regulators. A linear or an LDO (Low Drop-Out) regulator is in effect a variable resistor that is placed between the input power source (i.e. battery) and the load in order to drop and control the voltage applied to the load. Linear regulators have continuous operation, are typically easier to use, and are definitely a cheaper solution than any DC-DC regulator. Switching regulators provide the highest efficiency and produce the least amount of heat in a system. Therefore, switching regulators are suitable for applications where battery life and heat are important concerns. Efficiency of a regulator is defined as the ratio of output power provided by the regulator to the input power delivered into the regulator and is calculated from:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} I_{OUT}}{V_{IN} I_{IN}}$$

Figure 1 shows a simplified block diagram of a linear regulator with a resistive load R_{Load}. Linear regulators provide the most economical solution and are widely available from numerous vendors. Since the input current into a linear regulator is essentially identical to the output current ($I_{IN} = I_{OUT}$) then, efficiency of any linear regulator can be set by:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} I_{OUT}}{V_{IN} I_{IN}} = \frac{V_{OUT}}{V_{IN}}$$

Simply put, efficiency of a linear regulator is set by ratio of V_{OUT}/V_{IN}. Since the current consumed within the regulator is ignored, efficiency of a linear or LDO regulator is always LESS than V_{OUT}/V_{IN}. So, for a V_{IN}=4V input V_{OUT}=1V, the efficiency is always less than 25% and over 75% of the power provided by a source such as a battery is wasted and converted into HEAT. Efficiency of a linear regulator “looks” better when the difference between V_{OUT} and V_{IN} is reduced such that $V_{OUT} \approx V_{IN}$ (and $V_{OUT}/V_{IN} \approx 1$).

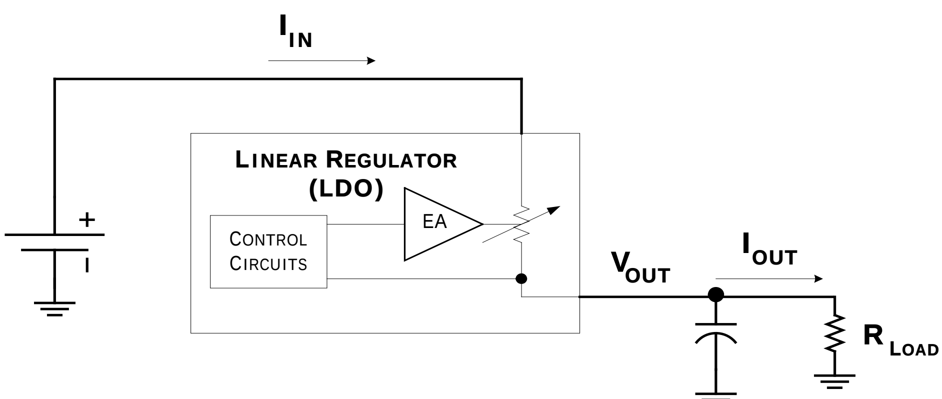

Figure 1. Simplified Block Diagram of a Linear or LDO Regulator.

Unlike linear regulators, switching regulators have non-continuous operation. Figure 2 shows a simplified block diagram of a synchronous step-down (Buck) switching regulator. Switches S1 and S2 are operated in a non-overlapping manner to create a digital pulse (V_A) that varies from zero to V_{IN}. This generated pulse (V_A) is filtered by off-chip passive components such as inductors and capacitors to produce a constant DC voltage at the output. This *loss-less* filter can be integrated in the same package along with the die to create a hybrid SiP or module solution.

Switching converters can have efficiencies in the range of 90% independent of input and output voltage ratios and are typically used in applications where efficiency (or battery life) is the most important concern. However, when they are compared to linear or LDO regulators, they cost more and are harder to implement.

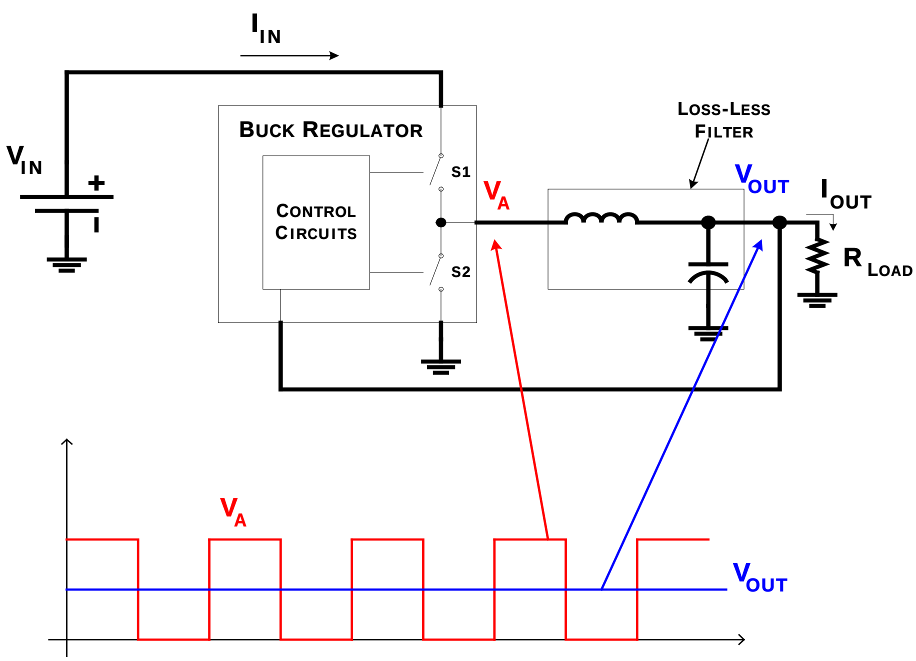

Figure 2. Simplified Diagram of a Buck Switching Regulator.

Assuming no loss in a switching Buck regulator (100% efficiency), the following relationship would be accurate:

$$V_{IN} I_{IN} = V_{OUT} I_{OUT} \Rightarrow I_{IN} = \frac{V_{OUT} I_{OUT}}{V_{IN}}$$

If a battery with 1000mAh (Milliamp Hour) capacity and an average voltage of 3V were used to power a 100mA load at 1V, the battery would last approximately 30 hours with a switching regulator. If a linear regulator were used in the same system, the battery would last less than 10 hours. This would be a 3X improvement in operating time and 3X reduction in generated heat and power loss. Reducing the heat in a portable device would in turn help to prolong the battery life as well since the excess heat will often degrade the performance of the battery.