The Ongoing Difficulty of Powering Microprocessors

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1.0 Introduction

It is commonly known in the power community that powering microprocessors is becoming more difficult. This brief is intended to provide a mathematical statement describing one aspect of this increasingly difficult problem.

$$\frac{L}{C} \propto V^4$$

2.0 Background

The power consumption in microprocessors is related to two factors.

The first of these is termed leakage and constitutes about one fourth of the overall current draw. Leakage is the result of steady-state current flowing through all active devices as sort of a bias current. Leakage is not directly related to clock speed, but leakage current is growing as a result of the thinner oxide layers and operations closer to threshold voltages that are common in high-speed microprocessors.

The second major factor is related to microprocessor clock speed. Energy is lost every time a microprocessor elemental device switches between logic levels. This lost energy is required to charge or discharge the parasitic capacitance associated with each cell and mathematically can be expressed as 1/2 CE^2 where C is the parasitic capacitance and E is the applied voltage. Since this phenomenon occurs with each clock cycle, calculating total power loss requires multiplying the loss by the microprocessor clock frequency making the power loss equal to $1/2CE^2F$, where F is the clock frequency.

With the losses increasing as the square of the applied voltage, it is clear the most direct path to lowering the overall power dissipation includes reducing the applied voltage. This makes it possible to add additional functionality to the microprocessor, while not increasing the power dissipation. The physics necessary to reduce the applied voltage is beyond the scope of this brief, but the need to reduce applied voltages for microprocessors as the industry moves into the future is a near certainty.

As can be seen in the next section, reducing the applied voltage creates a fourth order problem for the circuits providing power to microprocessors. It is this fourth order problem that has prompted industry leaders to identify power as the leading problem affecting efforts to advance the microprocessor functionality.

3.0 Derivation

For this derivation there are four assumptions:

1) The case under consideration is the worst case scenario – that being a downward step in current. In fact the limit case will be used for simplicity where the uP current is reduced from some fixed current to zero. In this case all the energy is transferred from the output inductance to the output capacitance.

2) The circuit contains only a VRM source with an output inductance L supplying a uP with a bypass capacitor C. With a MLCC bypass the series resistance and inductance of the bypass can be assumed to be so small they do not affect this analysis.

3) The power dissipation is constant. (Note: In reality the situation is actually may be more severe because the power dissapaited in the heat sink may actually increase over time.)

4) The voltage tolerance expressed as a percent of the supply voltage is small (a few percent) and held constant. That is, $\Delta V/V$ = constant.

E1 = Energy stored in output inductor = $\frac{1}{2} LI^2$.

E2 = Energy stored in output capacitor = $\frac{1}{2} CV^2$.

The starting point occurs when the energy in the inductor is transferred to the capacitor. The analysis is made when the current drawn from the uP goes to zero. This is a linear system easily analyzed at a limit condition. Small current changes will behave according to the same ratios.

$$E1 + E2 = \frac{C\left(V + \Delta V\right)^2}{2}$$

$$\frac{1}{2}LI^2 + \frac{1}{2}CV^2 = \frac{1}{2}C\left(V + V2\right)^2$$

$$LI^2 + CV^2 = C\left(V + V2\right)^2$$

$$= CV^2 + 2CV\Delta V + C\Delta V^2$$

Since $C\Delta V^2$ is a very small percentage, it is reduced to an insignificant number and can be removed.

3.0 Background Continued

$$= CV^2 + 2CV\Delta V$$

$$LI^2 = 2CV\Delta V$$

$$L = \frac{2CV\Delta V}{I^2}$$

$$\frac{L}{C} = \frac{2V\Delta V}{I^2}$$

Since power dissipation is a constant (V*I = constant) and removing all other constants:

$$\frac{L}{C} \propto V^3\Delta V$$

Since $\Delta V/V$ = constant:

$$\frac{L}{C} \propto V^4$$

This is the, “Equation of pain”.

4.0 Observations

The impedance of a VRM output filter must drop radically as the applied voltage to the microprocessor is reduced. This affects many current aspects of power design. One such area is the range of output voltage a VRM should be expected to accommodate. It is common for a VID (voltage identification data) table to cover a two-to-one range for output voltage. This is unnecessary, since there is no way for a VRM to accommodate the concomitant change in output impedance. Most VRM vendors already seem to know that this is not an appropriate voltage range, and some already optimize the VRM near the expected operating point.

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