# Cost-Effective Power Management Design for Advanced PC Motherboards

**Michael Huang**

### *Introduction:*

In such a rapidly changing information industry, it is essential to speed up the clock speed of CPU. Without increasing power dissipation, the required voltage for core part ($V_{core}$) in CPU such as INTEL's Pentium, Pentium II, Pentium III, AMD's K6 and K7 is keeping declining at the expense of increasing in current. To meet this requirement, the design of power converter on mother board has been changed into a Multiple Output Integrated Regulator instead of using the traditional Linear Regulator, Asynchronous Voltage Step-Down Regulator and Synchronous Voltage Step-Down Regulator. To go along with this trend, "Analog Integrations Corporation" introduces a new IC product AIC1570 that provides more integrating functions with higher performance and lower system cost.

### *Features of AIC1570:*

The function block diagram of AIC1570 is shown in Figure 1. As illustrated, the AIC 1570 integrated type regulator consists of three different output signals from PWM Controller, Linear Controller and Linear Regulator. It provides the required voltage sources for $V_{core}$, GTL bus (1.5 V) and clock driver circuit (2.5 V). For PWM Controller, the device uses two N-channel MOSFET to execute a standard synchronous voltage step - down and rectification. Cooperation of this with a 5-bit DAC converter can provide an accuracy within 1% of reference voltage source (1.3 V~3.5 V) for a CPU. This product perfectly meets the voltage source requirement for INTEL and AMD's CPU.

### *Basic Characteristics of AIC1570:*

a. The internal free-running oscillation frequency is 200 KHz. It can be modified up to 350 KHz by adding an external resistor Rocset, if necessary.

b. Full PWM Duty Ratio Range : 0 % ~ 100 %.

c. The Bandwidth of PWM Error Amplifier is 11 MHz, slew rate is 6 v/ms. These can provide an excellent Transient Response.

d. Linear Regulator can provide up to 450mA driving current.

e. Build in perfect protection function for over-current and over-voltage.

### *Fundamental Operating Principle of AIC1570:*

Upon an external input voltage 12 V feeding to an IC, AIC1570 starts to test and monitor three input voltage (3.3 V, 5 V and 12 V) signals sequentially by using Power On Reset (POR) function. In case any of the three input voltages exceeds the POR threshold voltage, AIC 1570 will trigger the soft start signal to accomplish a normal boot up and activate three output voltages. The essential purpose of POR is to eliminate a Special Power Sequence requirement. Therefore, AC1570 can widely work with a variety of manufacturer's Switching Power Supply (SPS).

### *(Ⅰ) Soft Start*

**Objective:** The PWM controller's output terminal is in parallel with many capacitors result a huge capacitance value. At the moment of starting the system, the zero initial output voltage of PWM Controller and its huge capacitance may sink too much inrush current through MOSFET. This overstress may destroy MOSFET if there is no current limiting protection. For the safety reason, AIC 1570 uses Soft Start to accomplish a safe start requirement.

**Method:** AIC 1570 uses a 10μA constant electric current provided inside the IC to charge the capacitor ($C_{SS}$) that is connected externally to SS pin. This makes PWM driving signal and its output voltage gradually increased in sequential cycles. After a certain amount of time, the driving signal will return to a normal controlled pattern by means of monitoring and detecting output voltage to accomplish a soft start to protect CPU.

PS. Suggested value to $C_{SS}$ 0.022μF ~ 0.1μF
Soft Start Time

$$T_S = \frac{CV}{I} \cong 4 \times 10^5 \times C \text{ (s)}$$

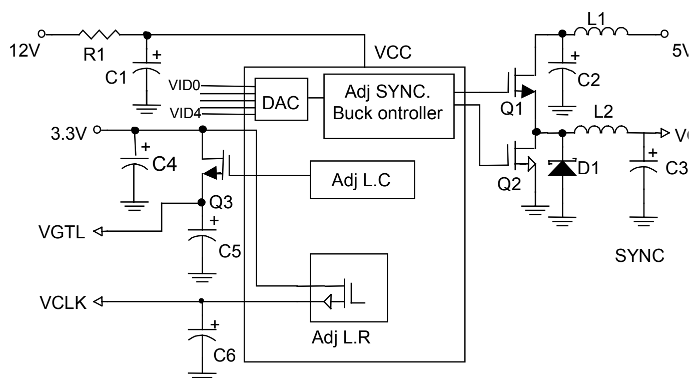


**Fig. 1 AIC1570 Simply Function Block**

## *(Ⅱ) Over-Current Protection*

AIC1570 is designed to have **individual** over-current protection setup for three output signals on PWM Controller, Linear Controller (LC) and Linear Regulator (LR). This is to protect the equipment at the output terminal.

**PWM Controller ：**

**Objective:** This is to prevent the converting elements such as MOSFET or AIC1570 from being damaged due to short circuit or surge current occurred on the output terminal of DC/ DC converter. Those phenomena might be as catastrophic as destroying the CPU at the output terminal.

**Method:** Utilize the internal conducting resistance $R_{DS(ON)}$ on High-Side MOSFET to detect the peak inductance current $I_{PEAK}$ at the output. To set the desired current protection level, the value can be estimated by the formula $I_{PEAK} = (I_{OCSET} \times R_{OCSET}) / (R_{DS-ON})$, where $I_{OCSET} \cong 200\mu A$ is the internal constant current source supplied by IC, $R_{OCSET}$ is the external resistance. This detection method can not only save the components cost (without adding external detection element such as Mn-

Cu wire at the output) but also increases the overall efficiency. However, the internal conducting resistance $R_{DS-ON}$ of MOSFET may vary with operating temperature and load current. To avoid the faulty operation of the over-current protection under normal loading, we have to consider the following factors to estimate the variables in the above formula for ideal over-current protection value:

a. The maximum $R_{DS-ON}$ at the highest junction temperature.

b. The minimum $I_{OCSET}$ from the specification table.

c. Determine $I_{PEAK}$> $I_{OUT(MAX)}$+ (inductor ripple current) / 2

PS. It is advised to have a ceramic capacitor $C_{OCSET}$ in paralleling with $R_{OCSET}$ in the circuit. This can prevent the faulty operation from feeding Switching Noise interference at the input terminal.

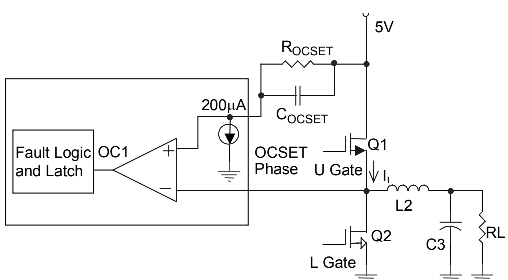


**Fig. 2 Over-Current Protection Circuit**

**LC / LR ：**

**Method:** To set the over-current protection by using the detection of output voltage and current for LR:

(I) The output current can be measured by using the internal over-current detector. It is considered as over-current when the output current exceeds the specified value 500mA.

(II) It is considered as over-current when the monitored feedback output voltage signal level (FB2) is below the specified value 0.96V.

### L.C over-current protection:

It is considered as over-current when the monitored feedback output voltage signal level (FB3) is below the specified value 0.96 V.

### Working principle:

The over-current signal (OC1, OC2) can be detected when short circuit or over-current happened to any one set of the output terminals. The AIC1570 will proceed the following detection or determination operation (see Figure 3):

a. Inhibit the three sets of output signal $V_{CORE}$, $V_{GTL}$ and $V_{CLK}$.

b. Reset initial signal：discharge/ charge soft-start signal.

c. Increment the counter.

d. Upon the soft-start signal being counted as three, AIC 1570 will trigger fault latch signal and disable the three sets of output signal.

e. After the output signal being turned off, it would not restart output signals again until the removal of anomalous operation, turning-off and re-feeding 12 V voltage signal to AIC1570.

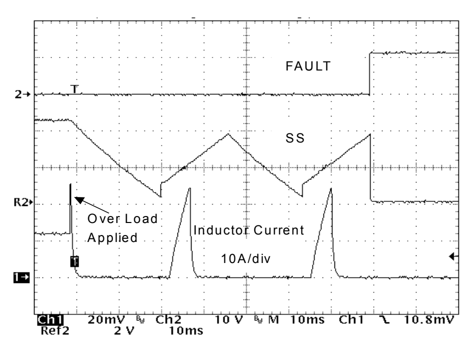


**Fig. 3. Over-Curretn Operation**

### (Ⅲ) Over-Voltage Protection

**Objective:** This prevents the malfunction of synchronous voltage step-down ($V_{CORE}=V_{IN}$) from the short circuit on Hi-side of MOSFET(Q1). The output voltage may exceed the critical voltage that CPU can tolerate, which causes the CPU be destroyed.

**Method:** Uses $V_{SEN}$ pin to detect the output voltage $V_{CORE}$ of PWM. When $V_{CORE}$ is larger than 115%$V_{DAC}$ , it indicates that the output voltage is too high. AIC1570 will take the following protection: Immediately start FAULT LATCH signal allowing the switching power supply (SPS) to turn off the main voltage source (12V/ 5V/ 3.3V) on the mother board.

Low signal at U gate and high signal at L gate will force the low-side MOSFET (Q2) be conducted that leads to decreasing the PWM output voltage ($V_{CORE}$). An additional over-current protection at 5V input terminal is to burn out the fuse at 5V input terminal. The cutting-off voltage source at 5V input terminal would lead to $V_{CORE} \cong 0V$, which can protect CPU from being destroyed.

### Selection of components:

### (Ⅰ) Selection of MOSFET:

The power loss of MOSFET can be clarified as two classes: conduction losses and switching losses. Conduction losses are caused by the power loss generated by the internal conducting resistance ($R_{DS-ON}$) in MOSFET. In general, the temperature coefficient of $R_{DS-ON}$ is positive because MOSFET is conducted by majority carries. In a synchronous voltage step-down circuit (BUCK), the conduction losses are related to both $R_{DS-ON}$ in MOSFET and the duty cycle of components.

**Conduction power loss at synchronous voltage step-down circuit (BUCK):**

$P_{CU} = I^2_{OUT} \times R_{DS-ON} D$ (Conduction losses on upper side of MOSFET)

$P_{CL} = I^2_{OUT} \times R_{DS-ON} (1-D)$ (Conduction losses on lower side of MOSFET)

**Switching losses :** Upon MOSFET executes ON/OFF state switching, the overlapping of $V_{DS}$ and $I_D$ would generate power losses. Its value is determined by input voltage, output load current and switching frequency.

**Switching power losses at synchronous voltage step-down circuit (BUCK):**

$P_{SU} = (I_O V_{IN} T_{SW} F)/2 + (C_{DS} V_{IN}^2 F)/2$ (Switching losses on upper side of MOSFET)

$P_{SL} = (I_O V_{IN} T_{SW} F)/2$ (Switching losses on lower side of MOSFET)

**Requirement for selecting MOSFET:**

a. Low $R_{DS-ON}$
b. Low $C_{ISS}$
c. Fast Reverse recovery time
d. Operating voltage and current must be in safe operating area (SOA)

### (Ⅱ) Selection of Schottky Diode:

There are two sets of driving circuit at synchronous voltage step-down circuit (BUCK). To avoid turning on MOSFETs on upper and lower side simultaneously, a dead-time is necessary to prevent from fatal damage. To keep output inductor current running continuously during the dead-time, it is necessary to use a free-wheeling diode to handle it. Generally speaking, the dead-time is shorter than 200 ns. It has a low efficiency drawback by using the parasitic diode on the low side MOSFET to act as free-wheeling diode, because with a large forward voltage ($V_{SD} \cong 0.9$ ~1.3V) and long reverse recovery time. Furthermore, they will generate a huge spike and ringing on $V_{DS}$ of low side MOSFET. To overcome this drawback, it usually uses a Schottky Diode with low forward voltage ($\cong$0.3~0.5V) and short reverse recovery time.

The conduction power losses of Schottky diode:

$P_{CR} = V_F I_{OUT}$ (1-D) In which $V_F$ is the Forward Voltage of Schottky diode.

**Requirement for the selection of Schottky diode:**

a. Low $V_F$
b. Low equivalent series resistance (Low ESR )
c. Short reverse recovery time
d. Sufficient Reverse Breakdown Voltage
e. Sufficient peak current ( $I_{D\text{-}PEAK} > I_{L\text{-}PEAK}$ )

### *(Ⅲ) Selection of input inductor and capacitor:*

In a circuit application on a mother board, 5 V main power provided by an external switching power supply, not only supply the step-down low voltage source (5V→$V_{CORE}$) for CPU but also supplies the voltage source demanded by other equipments. For a widely used synchronous voltage step-down circuit for $V_{CORE}$ a 200KHZ switching frequency ($F_{SW}$=200KHz) is commonly adopted in PWM –6IC. An undershoot and high frequency switching noise occur on 5 V input voltage source when MOSFET is on switching. To avoid the anomalous signal influencing other equipment that can cause system unstable, it is common to have a low pass filter (type II filter) at the input terminal. The filter is composed of an inductor (1μH) in series with input capacitor. This can eliminate high frequency signal interference.

The number of input capacitor: the maximum equivalent discharge current (IIN-RMS) that is based on the requirement for application circuit determines The specification of voltage endurance on input capacitor. The maximum voltage endurance of capacitor under the highest working environment temperature should be larger than 1.2 to 1.5 times as input voltage.

### *(Ⅳ) Selection of the output inductor and capacitor:*

In a synchronous BUCK circuit, a low pass filter, that is composed of output inductor and capacitor, can eliminate high frequency noise signal and adjust input power distributed evenly to the load. It is necessary to select the quantity and quality of output inductor and capacitor very carefully to meet a rigorous specification of transient converting voltage (reference VRM 8.1~ 8.4 or further) on CPU required by INTEL or AMD. Inductor stores energy in terms of current. The current cannot change instantaneously but going up or down linearly. The relationships among these variables:

Energy stored in inductor: $\omega_L = (1/2)\, L\, I^2$

Voltage change by inductor: $V_L = L \times d_{IL} / d_T$

Inductor current: $\Delta i_L = \dfrac{(V_{IN} - V_O)}{L} \times \Delta T$

**Suggestions to the selection of inductor:**

The inductance selection should guarantee those output load would maintain working in continuous conduction mode (CCM) whether it is in heavy or light load. The higher inductance it is, the smaller output ripple voltage and slower transient response at output load would be. The actual capacitor is composed of parasitic equivalent series inductors and equivalent series resistors. The output inductor cannot provide a huge instantaneous current required by CPU immediately when the output load changes from light to heavy load abruptly (CPU MODE：Stop Grant →Heavy Load). It must provided by output capacitor. In contrast, the output inductor cannot release excessive output current when the output load changes from heavy to light load abruptly (CPU MODE： Heavy Load → Stop Grant). It has to be absorbed by output capacitor. Thus, it is necessary to select output capacitor carefully to meet the requirements for DC/DC CONVERTER "Transient Response" and "Static Request" specified by CPU manufacture. (INTEL or AMD)

### Suggestions to the selection of capacitor:

The output capacitor should be composed of multiple small capacitors in parallel arrangement. As the number of paralleled capacitors becomes larger, the equivalent series resistance and equivalent series inductance would become smaller. If large capacitors are used instead, the output ripple voltage will become smaller. But the transient response at output load would become slower. It is a trade-off.

### Suggestions to PCB LAYOUT:

A 200KHz switching frequency is popularly used in most PWM IC (for CPU power application). The current will be charged/discharged between two configurations when upper/lower side MOSFET executes high speed ON/OFF switching states. During the states switching, the distributed inductance along the current path will generate voltage spike on switching elements. The spike voltage not only reduces the efficiency, but also produces noise signal. Worse yet it may generate over-voltage to destroy elements. Thus it needs special attention to select the proper specifications of switching elements (such as MOSFET, Diode etc.) in circuit application. Particularly, it is necessary to have a short path and wide metal trace along a path with large current on PCB layout. All of these can reduce the voltage spike.

(1) Must use ground plane configuration. The input capacitance ($C_{IN}$) should be as close to power switch as possible, i.e., to shorten the current path ( $C_{IN} \rightarrow$ Q1 $\rightarrow$ Q2 ).

(2) To shorten and widen the current path between switching elements (Q1 $\rightarrow$ L $\rightarrow$ Q2). An EMI could be easily generated because a fast voltage transition is executed on the path.

(3) The output capacitor ($C_{OUT}$) should be as close to output loading terminal ( CPU ) as possible. Doing so can meet the requirements for high slew rate, low inductance and low resistance.

(4) PGND and GND of AIC1570 should be connected in a shortest path and then connected with the whole ground plane.

(5) Compensation components for feedback signal should be configured as close as possible. To avoid interfering feedback signal with the noise signal, the components should be remote from PWM driving signal.

(6) To be decoupled directly to GND, a 0.1μF ceramic capacitor should be placed near to VCC pin.

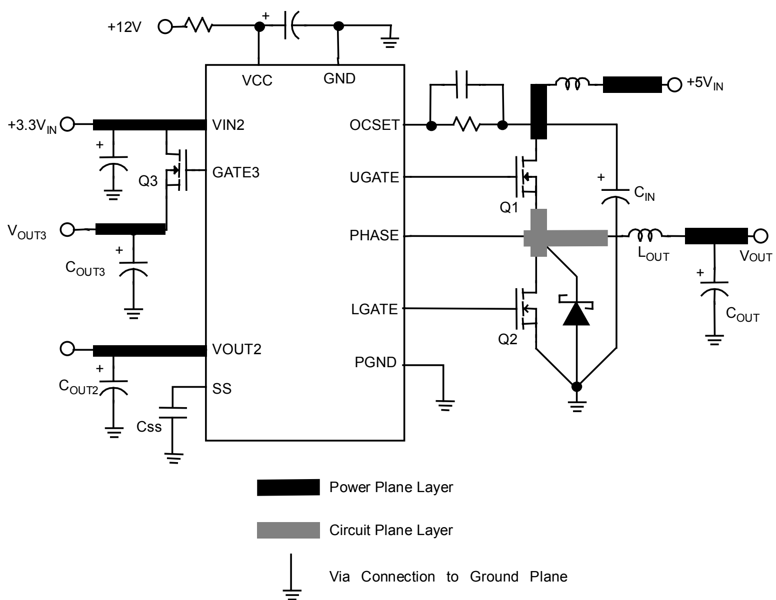


**FIG 4. Printed circuit board power plane and islands**

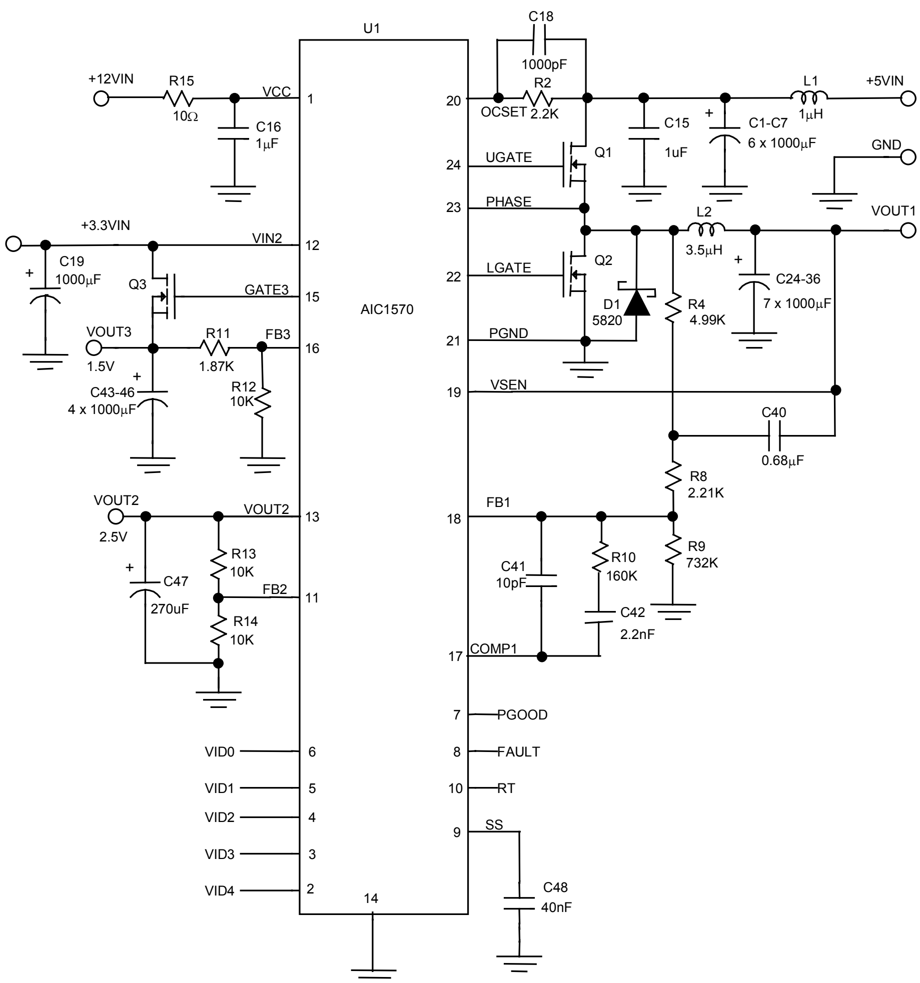


**FIG. 5 AIC1570 Application circuit diagram**

**List of materials to AIC1570 application circuit diagram:**

| Reference | Part Number | QTY | PKG | Vendor | Second Source |
|---|---|---|---|---|---|
| U1 | AIC1570CS | 1 PCS | SO24 | AIC | |
| Q1, Q2 | CEP6030L | 2 PCS | TO263 | CET | |
| Q3 | CET3055 | 1 PCS | SOT223 | CET | |
| L1 | 1μH | 1 PCS | | H & D | CAILCRAFT |
| L2 | 3.5μH | 1 PCS | | H & D | CAILCRAFT |
| D1 | 1N5820 | 1 PCS | | MOTOROLA | |
| R2 | 2.2KF | 1 PCS | 0805 | Various | |
| R4 | 4.99KF | 1 PCS | 0805 | Various | |
| R8 | 2.21KF | 1 PCS | 0805 | Various | |
| R9 | 732KF | 1 PCS | 0805 | Various | |
| R10 | 160KF | 1 PCS | 0805 | Various | |
| R11 | 1.87KF | 1 PCS | 0805 | Various | |
| R12,R13,R14 | 10KF | 1 PCS | 0805 | Various | |
| R15 | 10RJ | 1 PCS | 0805 | Various | |
| C 1~7, 24~36<br>C43~46, C19 | 1000μF | 18PCS | | SANYO | |
| C15,C16 | 1μF | 2 PCS | 0805 | Various | |
| C18 | 1000pF | 1 PCS | 0805 | | |
| C40 | 0.68μF | 1 PCS | 0805 | Various | |
| C41 | 10pF | 1 PCS | 0805 | Various | |
| C42 | 2.2nF | 1 PCS | 0805 | Various | |
| C47 | 270μF | 1 PCS | | Various | |
| C48 | 40nF | 1 PCS | 0805 | Various | |

### *Conclusion:*

In a rapidly changing electronic industry, the challenge to R & D engineers is not only to design a quality product but also to meet low cost requirement. Based on these, Analog Integrations Cooperation introduces an integrated regulator that includes PWM Controller, Linear Controller, and Linear Regulator. That is, it can provide three different output signals. Not only have a quality function and simple design, but also meets requirement for low cost.