Everything You Need to Know About The Motherboard Voltage Regulator Circuit

By Gabriel Torres on February 10, 2010

Introduction

If you are willing to learn more about motherboard quality you must deeply study the voltage regulator circuit, which is in charge of taking the voltage provided by the power supply – namely +12 V – and converting it into the appropriate voltage required by the CPU, memories, chipset and other circuits present. In this tutorial we will present an in-depth trip inside the motherboard voltage regulator circuit, showing you how to identify this circuit, how it works, what the most common projects are and how to identify good-quality components.

The quality of the voltage regulator circuit is one of the best ways to have an idea about the overall motherboard quality and life-span for several reasons. A good voltage regulator won't have any fluctuations or noise on its outputs, providing the CPU and other components with a clean and stable voltage, allowing them to work perfectly. A bad voltage regulator can lead to fluctuations or noise on the voltage that will lead to malfunctions like the computer crashing, resetting and presenting the infamous Blue Screen of Death on Windows.

If this circuit uses low-quality electrolytic capacitors they will leak, swell or even explode. Frequently when a motherboard dies it is this circuit that goes bad. So having a good-quality voltage regulator circuit will ensure that you will have a stable system that will last for years.

Recognizing this circuit is pretty easy. Since it is the only circuit on the motherboard that uses chokes (a kind of coil), locate the chokes and you will have located the voltage regulator circuit. Usually this circuit is around the CPU socket, but you will find some chokes spread on the motherboard, usually near the memory sockets and near the south bridge chip, as they will be providing the right voltage to these components.

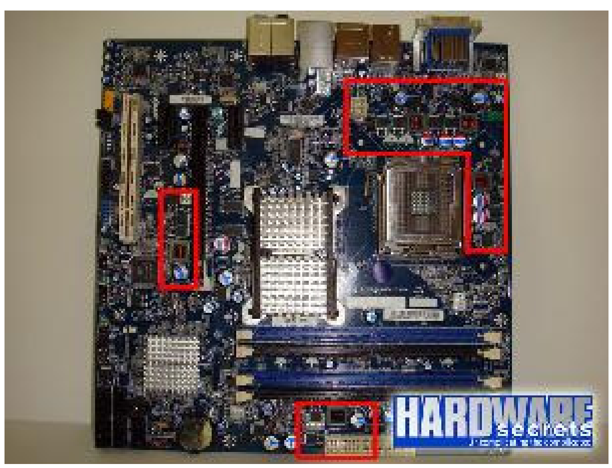

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Figure 1: Voltage regulator circuit.

Before explaining exactly how this circuit works, first let's get you acquainted with the main components found on the voltage regulator circuit.

Meeting The Components

The main components of a voltage regulator circuit are the already mentioned chokes (which can be manufactured using two materials, iron or ferrite), transistors and electrolytic capacitors (good motherboards will provide solid aluminum capacitors, which are better). The transistors used on the voltage regulator circuit are manufactured under a technology called MOSFET (Metal-Oxide Semiconductor Field Effect Transistor) and many people call them simply "MOSFET" (some motherboards, in particular the ones from MSI based on "DrMOS" technology, use integrated circuits instead of transistors). Some motherboards come with a passive heatsink on top of these transistors to cool them down, which is a desirable feature. There are other very important components present on this circuit, especially integrated circuits. You will always find an integrated circuit called "PWM controller" and in good designs a tiny one called "MOSFET driver". We will explain what they do later.

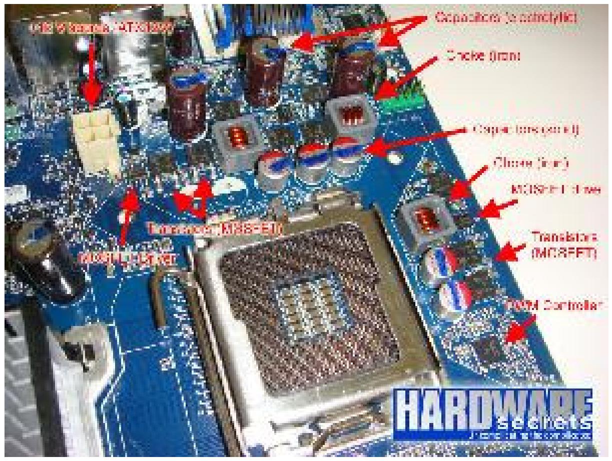

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Figure 2: A close-up on the main voltage regulator circuit.

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Figure 3: Motherboard with passive heatsink on top of the transistors.

Now let's talk a little bit more about each component.

As mentioned, you can find two kinds of chokes on the voltage regulator circuit: iron or ferrite. Ferrite chokes are better as they provide a lower power loss compared to iron chokes (25% lower, according to Gigabyte), a lower electromagnetic interference (EMI) and have a better resistance to rust. It is easy to tell them apart: iron chokes are usually "opened" and you can see a thick copper wire inside, while ferrite chokes are "closed" and usually have a marking starting with the letter "R" on top. On Figures 4 and 5 we show you the difference between them. There is one exception, though. There are ferrite chokes that are big, rounded and opened, shown in Figure 6. It is very easy to identify this kind of ferrite choke, as it is rounded instead of squared.

The voltage regulator circuit will have one choke per "phase" or "channel". Don't worry about this now as we will explain what this is in detail later.

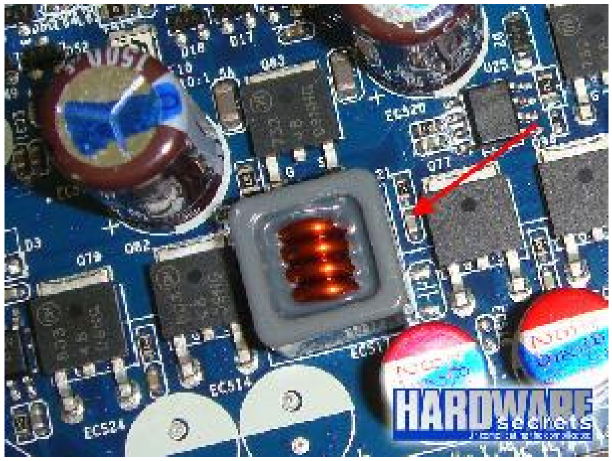

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Figure 4: Iron choke.

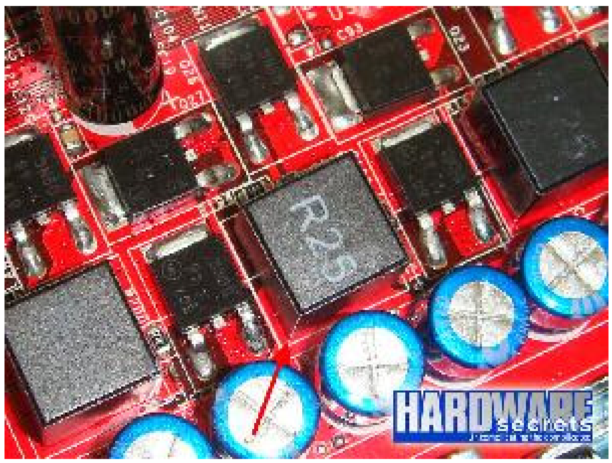

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Figure 5: Ferrite choke.

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Figure 6: Ferrite Choke.

Meeting The Components (Cont'd)

Although most motherboards use MOSFET transistors on the voltage regulator section, some transistors are better than others. The best transistors are the ones with lower switching resistance – a parameter called RDS(on). These transistors produce less heat (16% less heat compared to traditional MOSFET, according to Gigabyte) and consume less power to its own operation, meaning higher efficiency (i.e., the motherboard and CPU will consume less power). They are physically smaller than traditional transistors. An easy way to differentiate the two is by counting the number of available terminals. Traditional transistors have three legs, with the center leg usually cut, while transistors with low RDS(on) have four or more legs and all of them are soldered to the motherboard.

You can see the difference between the two by comparing Figures 7 and 8.

The voltage regulator circuit will have two transistors per “phase” or “channel”, one called "high side" and the other called "low side". Cheaper motherboards instead of using one MOSFET driver integrated circuit per channel uses one extra transistor per channel to perform this function and thus such motherboards will have three transistors per channel (phase) instead of two. Because of that the best way to count and identify phases is by counting the number of chokes, not the number of transistors.

Some motherboards, especially the ones from MSI based on their "DrMOS" technology, will use one integrated circuit replacing the "high side" MOSFET, the "low side" MOSFET and the driver MOSFET, and therefore on such motherboards you will find one integrated circuit per phase and no transistor.

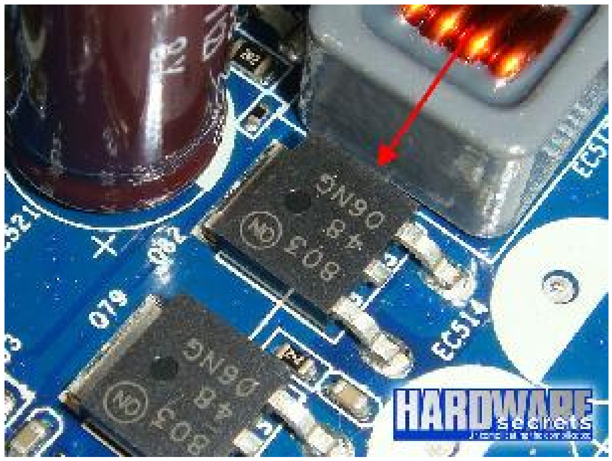

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Figure 7: Traditional MOSFET.

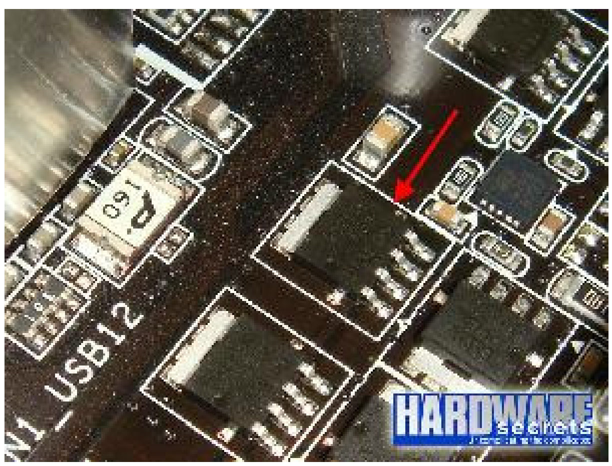

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Figure 8: MOSFET with low RDS(on).

The capacitors used on the voltage regulator circuit can be of the traditional electrolytic type or solid aluminum ones, and we’ve already shown the physical difference between them in Figure 2. Solid aluminum capacitors are better than regular ones as they do not swell or leak. If your motherboard uses regular caps, you should discover their manufacturers. Capacitors manufactured in Japan have the tradition of being immune to swelling, leaking and explosions. We have already published a detailed tutorial on how to identify Japanese caps and you should read it.

Each voltage output is controlled by an integrated circuit called the PWM controller. The motherboard will have one of this per voltage level, i.e., one for the CPU, one for the memories, one for the chipset, etc (most PWM controllers are able to control two independent voltage levels). If you look around the CPU socket you should be able to find the PWM controller for the CPU voltage, see Figures 2 and 9.Some motherboards have the PWM circuit running at a higher frequency, which reduces power loss (in other words, it increases efficiency, i.e., lowers the amount of power consumed by the motherboard/CPU). The manufacturer will clearly advertise this feature if your motherboard has it.

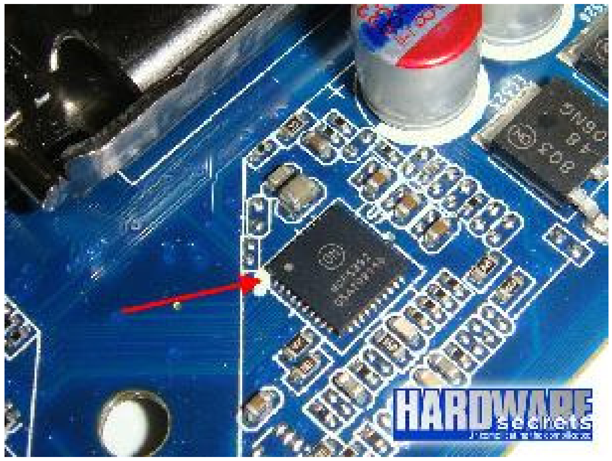

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Figure 9: PWM controller.

Finally we have a smaller integrated circuit called MOSFET driver. The voltage regulator circuit will use one MOSFET driver per phase (channel), so each integrated circuit will drive two MOSFETs. Cheaper motherboards will use another MOSFET in the place of this integrated circuit, so in motherboards that use this design you won't find this integrated circuit and each phase will have three transistors, not two as usual.

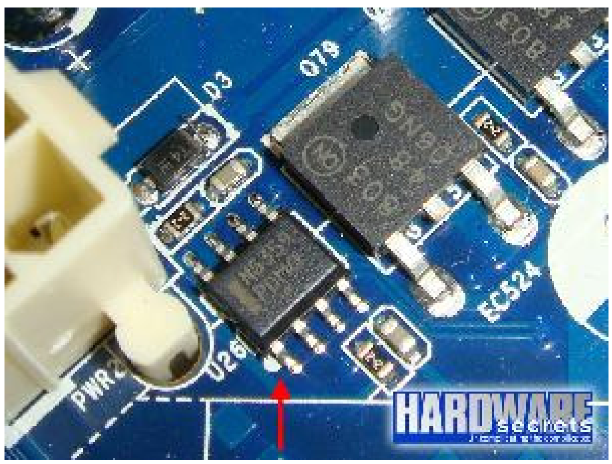

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Figure 10: MOSFET driver.

Phases (Channels)

The voltage regulator may have several power circuits working in parallel to provide the same output voltage – say the CPU core voltage. They, however, are not working at the same time: they are working out-of-phase and hence the name "phase" to describe each circuit. We will explain in details in the next page how this works, so don't get scared. We want to present an introduction to this subject, since manufacturers and enthusiasts like to discuss the number of "phases" a motherboard has a lot.

Let's take the CPU voltage regulator circuit. If this circuit has two phases (or channels), each phase will be operating 50% of the time in order to generate the CPU voltage. If this same circuit is constructed with three phases, each phase will be working 33.3% of the time. With four phases, each phase will be working 25% of the time. With six phases each phase will be working 16.6% of the time. And so on.

There are several advantages in having a voltage regulator circuit with more phases. The most obvious is that the transistors will be working less loaded, which provides a higher life-span to these components and a lower operating temperature. Another advantage is that the more phases you have usually the output voltage is more stable and also the noise level is lower.

Adding more phases require adding more components, which increase the cost of the motherboard:

cheaper motherboard will have fewer phases, while more expensive ones will have more phases.

Also it is very important to clarify that when a manufacturer says that a motherboard has six power phases, it is referring only to the CPU main voltage (Vcore). On next page we will explain in more details what happens when the CPU requires more than one voltage.

Each voltage phase or channel uses one choke, two or three transistors (or a single integrated circuit replacing these transistors), one or more electrolytic capacitors and one MOSFET driver integrated circuit – this last component can be replaced by a transistor, as which is the case with low-end motherboards. As you can see, the exact number of components will vary. The only component that is present with always the same count is the choke, so the best way for you to know how many phases a given voltage regulator circuit has is by counting the number of chokes (pay attention because there are exceptions; we will explain them next). For example, the motherboard in Figure 11 (the same board shown before on Figures 1 and 2) has three phases.

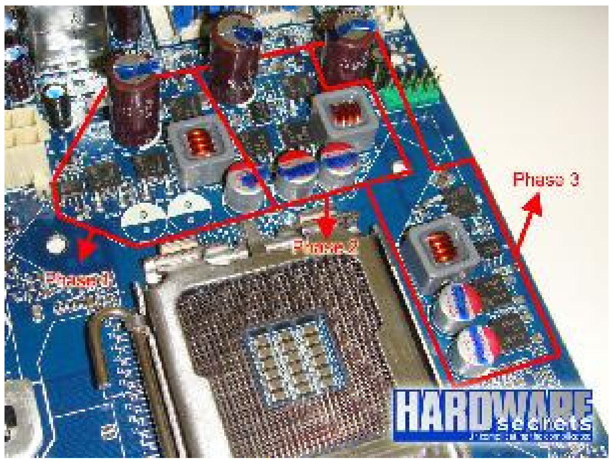

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Figure 11: Phases.

But there is one caveat. On some motherboards the phase that controls the memory or the chipset voltage is located close to the other phases, making you to have a wrong phase count if you simply count the number of chokes present near the CPU socket. We show this case in Figure 12: even though the portrayed motherboard has four chokes, it is a three-phase motherboard, as only three of the phases are used to generate the CPU main voltage (Vcore); on this motherboard the fourth phase is used to generate the memory voltage. We will teach how to get the exact phase count in just one second.


click to enlarge
Figure 12: Motherboard with three phases, not four as you could assume.

It is wrong to assume that only chokes near the rear end of the motherboard should be counted, ignoring chokes located on the side of the board: in Figure 11 you can see a motherboard with a choke located on the side that belongs to the CPU voltage regulator circuit…

Since all chokes that are producing the same output voltage have their outputs connected together, only chokes that have their outputs connected together should be counted. This can be done by following each choke output on the solder side from the motherboard. In Figure 13 we show the solder side from the motherboard shown in Figure 12. As you can see, only three chokes are connected together, the output from the fourth choke is going down to the memory sockets (we know this because this was a socket 775 motherboard, where the CPU only requires a single voltage; detailed info will be given in the next page).

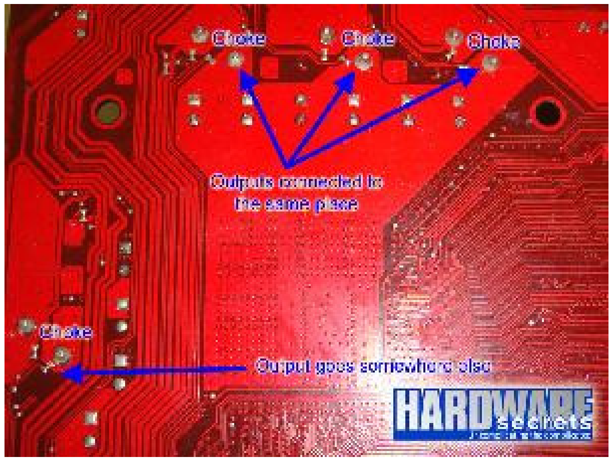

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Figure 13: Correct way of counting chokes.

On some motherboards you may not clearly see the connection between phases like we are showing in Figure 13. In this case you have to get a multimeter and check which chokes are connected together. You can either but your multimeter on its continuity scale (if it has one – usually beeping when the probes are "shorted", indicating that there is connection) or resistance scale (which will show zero ohm when there is a connection). On Figures 14 and 15 we show another motherboard with four chokes where the connections of the chokes isn't clear like on the motherboard from Figure 13. With a multimeter we discovered that three of the chokes were connected together, thus this was a "three-phase" motherboard. The fourth choke was feeding something else (the CPU integrated memory controller, as we will explain in the next page).

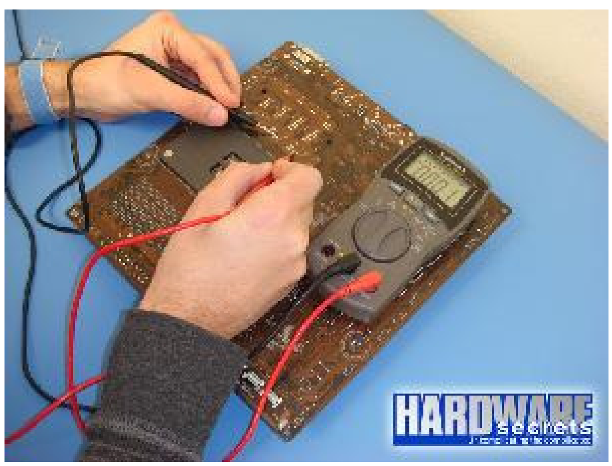

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Figure 14: These two chokes are connected together.

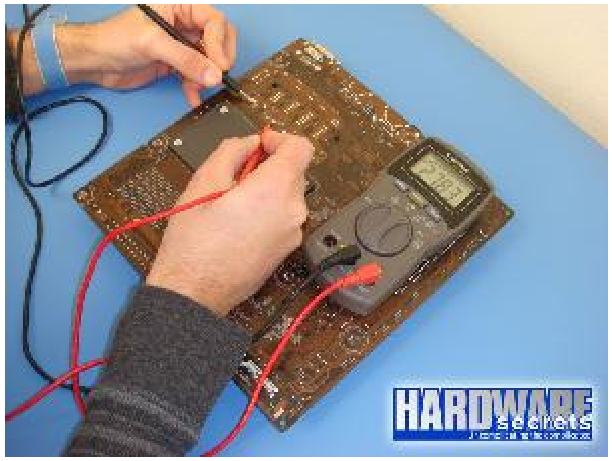

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Figure 15: These two chokes aren't connected together.

CPUs That Require More Than One Voltage

Newer CPUs will require more than one voltage. Even though all CPUs from AMD have an integrated memory controller, only socket AM3 CPUs require a separated voltage for this circuit. So on socket AM3 motherboards the voltage regulator circuit will generate two separated voltages for the CPU, one for the "main" part of the CPU ("Vcore") and another for the integrated memory controller. That is why we knew, in Figure 15, that the extra phase was for feeding the CPU integrated memory controller: because that was a socket AM3 board.

With Intel CPUs, only socket 1156 and socket 1366 CPUs have an integrated memory controller. So on these motherboards the voltage regulator circuit will generate two voltages, one for the "main" part of the CPU ("Vcore") and another for the integrated memory controller ("VTT"). On socket 1156 motherboards supporting CPUs with integrated video controller (e.g., the ones based on H55 and H57 chipsets) the voltage regulator circuit will generate a third voltage for the CPU, to be used by the integrated video controller ("VAXG").

On motherboards where the voltage regulator circuit provides more than one voltage to the CPU, the manufacturer will refer to it like "x+y" or "x+y+z", where "x" is the number of phases for the CPU main voltage ("Vcore"), "y" is the number of phases for the CPU integrated memory controller and "z" is the number of phases for the CPU integrated video controller. The motherboard shown on Figures 14 and 15 had a "3+1" configuration, for example.

Below we summarize what kind of motherboard feeds the CPU socket with more than one voltage.

Socket	**Voltages for the CPU**
754, 939, 940, AM2, AM2+, 775 and older	One
AM3, 1156, 1366	Two
1156 with H55, H57 and Q57 chipsets	Three

Although in this tutorial we focused on the voltages required by the CPU, all motherboards will have at least one phase for feeding the memories and one phase for feeding the chipset. If you look around you will be able to spot these phases (see Figure 18), unless when the memory phase is placed close to the CPU phases, like it happened on the example from Figure 12.

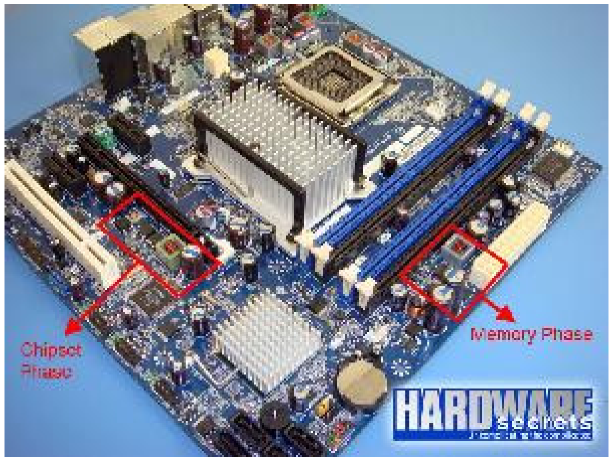

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Figure 16: Memory and chipset phases.

How it Works

The voltage regulator circuit gets the +12 V voltage present on the ATX12V or EPS12V connector found on the motherboard and converts it to the voltage required by the component that the voltage regulator is connected to (CPU, memory, chipset, etc). This conversion is done using a DC-DC converter, also known as switching-mode power supply (SMPS), the same system used inside the PC main power supply.

The heart of this converter is the PWM (Pulse Width Modulation) controller. This circuit generates a square-wave signal that will drive each phase, with the duty cycle from this signal varying depending on the voltage that the circuit wants to produce (duty cycle is the amount of time the signal stays on its higher value; for example, a signal with 50% duty cycle will spend half the time on its lower value - usually zero volt - and the other 50% of the time on its higher value -- which means +12 V on the case of the voltage regulator circuit.

The value of the output voltage the voltage regulator circuit must produce is read from the CPU "voltage ID" (VID) pins, which provide a binary code with the exact voltage that must be supplied. Some motherboards allow you to manually change the CPU voltage inside the motherboard setup program. What the setup does is to change the code that is read by the PWM controller, so the controller will change the CPU voltage according to what you've configured. Even though we are talking about the CPU, the same idea applies for the memory and the chipset.

The DC-DC converter is a closed loop system. This means that the PWM controller is constantly monitoring the outputs of the voltage regulator. If the voltage on the output increases or decreases the circuit will readjust itself (changing the frequency of the PWM signal) in order to correct the voltage. This is done through a current sensor, since when current consumption increases the output voltage tends to decrease and vice-versa.

In Figure 17 we have the block diagram of a PWM controller usually found on the CPU voltage regulator circuit (NCP5392 from On Semiconductor). On this block diagram you can easily identify the voltage ID pins (VID0 through VID7), the loopback pins (CS, Current Sensor pins, located on the left side) and the outputs to drive each phase (G pins, located on the right side). As you can see, this integrated circuit can control up to four phases.

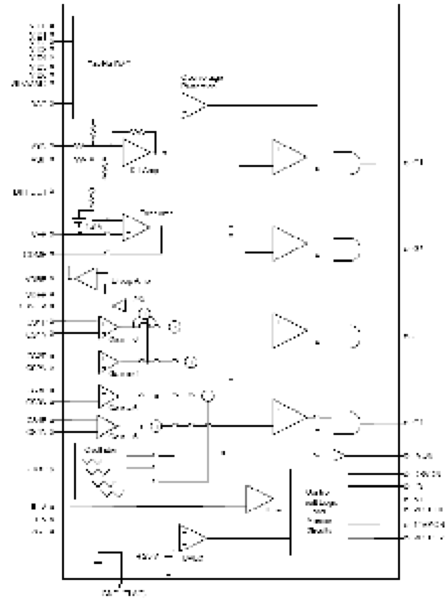

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Figure 17: PWM controller.

Each phase uses two transistors and one choke. The PWM controller does not provide enough current to switch these transistors, so a MOSFET driver is required for each phase. Usually this driver is made with a small integrated circuit. In other to cut costs some manufacturers use a discrete driver using an additional transistor on very low-end motherboards.

In Figure 18, you can see the basic schematics of one phase from a motherboard (the loopback connection is missing on this diagram) driven by an NCP5359 MOSFET driver. The driver and the MOSFET transistors will be fed by the +12 V voltage provided on the ATX12V or EPS12V connector (where it is written "10 V to 13.2 V" and "4 V to 15 V"). You can see on this diagram the two MOSFETs (the top one is the "high side" and the bottom one is the "low side"), the choke and the capacitors. The loopback signal will be provided by linking two wires connected in parallel to the choke to the PWM controller CS+ (CSP) and CS- (CSN) pins. The PWM pin is connected to the PWM output provided by the PWM controller and the EN pin is the "enable" pin, which activated the circuit.

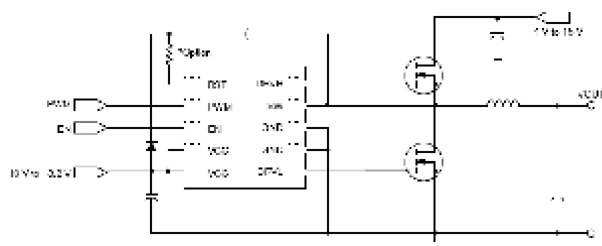

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Figure 18: Phase simplified schematics.

As you can see in Figure 17, there is one PWM output for each phase. As explained, the PWM signal is a square waveform where its width (duty cycle) changes depending on the voltage you want (that is why this technique is called Pulse Width Modulation). Assuming that the output voltage is stable, all PWM signals will have the same duty cycle, i.e., the size of each "square" on the signal will be the same. These signals will, however, have a delay between them. This delay is also known as phase-shift.

For example, on a circuit with just two phases, the two PWM signals will be mirrored. So while phase 1 is turned on, phase 2 will be turned off and vice-versa. This will ensure that each phase will work 50% of the time. On a circuit with four phases, the PWM signals will be delayed in such way that phases will be activated in sequence: first phase 1 is activated, then phase 2, then phase 3 and then phase 4. While one phase is turned on all others are turned off. In this case, each phase will be working 25% of the time.

The more phases you have, less time each phase will be turned on. As explained earlier, this makes each phase to dissipate less heat and each transistor to work less, which provides a higher life-span to this component.

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