Power Delivery for platforms with Embedded Intel® Atom™ processors

Power Supply Solutions and Recommendations from the Embedded and Communications Group

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Background

High performance-low power Intel® Atom™ processors are being designed into a wide range of embedded applications that would not be practicable with mobile, desktop or server CPUs. While many Intel Atom processor power supply requirements have a lineage that trace back to more conventional mobile and desktop processors, there are differences due not only to the reduced operating current, but also the high levels of integration. This paper explains what is required to deliver power to embedded platforms with Intel Atom processors. The significance of the Intel® Mobile Voltage Position specification is explained as well as the roles of the System Management Controller and Power Management Integrated Circuits.

Audience

For a System Architect, this paper will explain the types of power supplies that are used in embedded Intel® Atom™ platforms, and the merits of each. Also, the roles of the Intel® MVP power supply controllers, System Management Controller, and Power Management Integrated Circuits are explained.

For the Platform Design Engineer, this paper will explain the merits of using a mix of linear and switching voltage regulators for powering an embedded Intel® Atom™ processor system. The Intel IMVP specification is introduced as well as its role in powering the CPU core and graphics core of the Intel Atom processor CPU. The purpose of the System Management Controller will be explained and design options in both system control and power delivery will be presented.

For the Power Supply Design Engineer, several real world solutions are presented with part numbers from a number of third party vendors. Also shown are valid power supply solutions using both discrete Intel® MVP
controllers and the more integrated solutions which use Power Management Integrated Circuits.

When engineers talk about computer power supplies, they often mean power convertors. The real power supply would be a battery or AC source. The power converters take one voltage and convert it to another voltage as required by the chips or subsystem in the computer. There are a number of ways to convert one voltage to another; linear voltage regulators, transformers, motor-generators, charge pumps, and switching voltage regulators all have their place. In computers, linear voltage regulators and switching regulators dominate. The following is a review of the basic tenets of linear and switching voltage regulators.

The linear regulator input current equals the output current.

The switching regulator input power equals the output power.

In a linear voltage regulator, all of the input current goes through a “linear” pass element which burns off excess voltage and power before going to the load. In this simple schematic, the pass element is shown as a variable resistor:

Figure 1: Linear voltage regulator

![Linear Voltage Regulator Diagram]

Considering a case where Vin is 5V and Vout is 2V. The linear pass element must drop 3V to go from 5V to 2V. If the load current is 1A then the power which must be dissipated is 3 watts.
As the difference between Vin and Vout increases, linear regulators must dissipate more heat and waste more power.

In real world linear voltage regulators, the variable resistor is replaced by a transistor, and a feedback and control system continuously adjusts the effective resistance to maintain the desired output voltage. The simplest linear voltage regulators are often referred to as “Three Terminal Regulators” because the only electrical terminals are the input, output, and return or ground terminal.

Simple three terminal voltage regulators are still commonly used on modern computer motherboards. Sometimes other features are needed that three terminal regulators cannot provide, these features might include the ability to turn on or off via an input enable pin, power good output status pins, or voltage margining capability.

**Linear Regulator vs. Low Drop Out (LDO)**

Often linear regulators are referred to as LDOs. Low Drop Out (LDO) refers to the minimum voltage drop required to maintain regulation. The industry standard 7805 linear three terminal voltage regulator requires at least 7V at the input to maintain a 5V output or it is not considered an LDO. In the same application a true LDO might be able to maintain regulation with only 5.5V on the input.
Switching Voltage Regulators

In applications where too much power would be wasted using a linear voltage regulator, switching regulators (that is, switchers) can be used. Switchers are more complex than linears, but the improved energy efficiency and reduced power dissipation (heating) often make switchers the only suitable solution.

Figure 2 shows a simplified switching (step down, that is, Buck) regulator.

![Figure 2: A simplified switching regulator](image)

The switch alternates between being connected to either Vin or zero Volts. The rate at which the switch alternates can vary, but 300k switches per second is a typical switching frequency. The inductor smoothes out the alternating switch voltage and provides a DC voltage to the load that is equal to the average voltage coming out of the switch. Assuming for now that the switch and the inductor are ideal components, then an interesting thing comes out of the efficiency calculations. The switch either has current flowing through it but no voltage drop, or a voltage drop across it but no current through it. In other words at no time is there both current flowing through the switch and a voltage drop across the switch. The result is no power loss! To vary the output voltage of a switching regulator you simply vary the amount of time the switch spends at 12V vs. 0V. This is known as a variable duty cycle or pulse width modulation.
Real switchers do not use a switch as shown above; rather they use mosfets as shown in the simplified schematic diagram of Figure 3:

**Figure 3: Mosfets in real switchers**

![Schematic diagram of mosfets in real switchers](image)

Even this model is simplified; a more complete schematic will include the mosfet drivers, as well as the voltage regulator controller. Often the controller will have an integrated mosfet driver; sometimes the controller will even include the main switching transistors. Figure 4 shows the schematic of a real switching voltage regulator:
Of course switching voltage regulators do not use perfect components however efficiencies over 90 percent can be obtained.

**Intel® Mobile Voltage Positioning (Intel® MVP)**

Intel® Atom™ processor CPUs require a core power supply that meets the Intel Mobile Voltage Positioning (version 6) specifications. Some Intel® Atom™ processor CPUs require IMVP controlled voltages for both the CPU core and the graphics core. As the name implies, the most important part of the IMVP specification is setting the voltage. The IMVP 6 specification has a table of voltages that correspond to a set of Voltage Identification (VID) codes. The CPU controls a seven bit parallel bus that tells the CPU core voltage regulator what the voltage output voltage should be at any instant. By allowing the CPU to control its own operating voltage it is able to dynamically optimize its operating power and performance.

Initially the requirement of using an IMVP-6 controller for powering an Intel® Atom™ Processor CPU might seem like just another technical
hurdle, but it does come with significant benefits. The IMVP specification defines much more than just the required output voltage. Included in the specifications are the required input pins and control signals, output signals, softstart, restart, voltage slew-rate control, and a number of protection mechanisms.

There are many third party vendors with IMVP-6 compliant voltage regulators, including the following:

- Analog Devices*
- Intersil *
- Linear Technology*
- Maxim*
- On Semiconductor*
- RichTek*
- Rohm LSI Systems*
- Semtech*
- Texas Instruments*

Since the IMVP specifications were targeted at mobile and low power systems, there are many power saving schemes available and operation over a wide range of input voltages are supported, from a single cell battery to more than 24V for some AC power adapters.

As of late 2010 all Intel Atom processors include the seven bit external VID buss and expect the CPU core (VCC) voltage to follow the IMVP-6 or IMVP-6.5 specification. The Intel Atom processors with an integrated graphics core also require the graphics core voltage (VNN) to follow the IMVP-6 specification. If the graphics core is integrated, the VID lines are shared (multiplexed). In this case the two VID identification pins indicate whether the VID code is for the CPU core or the graphics core.
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**System Management Controller**

A component that may be new to Intel Atom processor platform designers is the System Management Controller (SMC). In an embedded platform the SMC is responsible for management of all the voltage regulators, making sure they turn on and off in the proper sequence, turning on and off peripherals as required to save power, and controlling the IMVP voltage regulators. In legacy systems, these functions may have been handled by the Input Output Hub (IOH), or Super Input Output Controller. For the embedded Intel Atom processor platform you have at least two options, make an SMC using glue logic, programmable logic devices or microcontrollers or use a Power Management Integrated Circuit (PMIC) that was designed with guidance from Intel for the specific Intel Atom processor platform. Figure 5 shows the connections between the VCORE IMVP 6 regulator, the SMC, and an Intel Atom processor CPU:

![Figure 5: Intel® MVP 6 regulator, SMC and Intel® Atom™ processor connections](image-url)
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**Power Management Integrated Circuit (PMIC)**

Controlling and sequencing as many as twenty power rails, through all of the power states, startups, restarts, and shutdowns is a bigger challenge than most designers will care to tackle. To make things easier Intel has worked with third party vendors to create Power Management Integrated Circuits (PMICs).

The PMICs integrate the SMC, one or two IMVP switchers, all the linear regulators and power switches and more into one package. For control, the PMIC uses all the VID lines, VID enable lines, and a SPI bus from the processor. The PMICs handle all the power states and power sequencing. Many PMICs have other capabilities including:

- Real Time Clock
- Battery Charger / Controller
- Coulomb Counter / Battery Charge Gauge
- System Clock Generator
- ADC
- Digital I/O

Here is a list of manufacturers that have made PMICs for Intel Atom processor platforms with part numbers:

- **Dialog Semiconductor**
  - DA6001 for the Intel® Atom™ processor Z500 series
  - DA6001 for the Intel® Atom™ processor E600 series
- **Freescale Semiconductor**
  - SC900841 for the Intel® Atom™ processor Z500 series
  - SC900844 for the Intel® Atom™ processor Z600 series
- **Maxim**
  - MAX8958 for the Intel® Atom™ processor Z600 series
- **Renesas Electronics Corporation (NEC)**
  - uPD9975 for the Intel® Atom™ processor Z600 series
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- uPD9976 for the Intel® Atom™ processor Z6xx series and Intel Platform Controller Hub MP20
- ROHM Semiconductor
  - BD959x Series for the Intel® Atom™ processor E600 series

For the Intel® Atom™ processor Z500, E600, and Z600 series, Intel expects that system design engineers will use a PMIC from a third party vendor that was designed specifically for that CPU.

Customer Reference Board Examples

Intel® Atom™ processor Z500 series

- The CPU core voltage is supplied by an IMVP 6 controller with external mosfets, converting from the +V12S_CPU rail.
- The VDDQ 1.8V rail is supplied by a switcher converting from 12V. The controller is a TPS51116. The same controller also has an internal linear supply that supplies the 0.9V required for memory termination.
- There are two 1.05V rails each with its own enable pin. These rails are created by single phase switchers converting from 12V. Both of the 1.05V rails are generated using a single MAX8717 controller. The bias supply for the controller is the V5S rail.
- The 1.5V rail is supplied by a MAX1515 switcher with internal mosfets converting from the +V3.3S rail
- The System Management Controller is a Renesas* H8S/2117 embedded microcontroller.
Intel® Atom™ processor 400 – 500 series

The Intel® Atom™ processor D510 customer reference board uses:

- A Vcc Core is supplied by an NCP5380 IMVP 6 switcher converting from the VCC5_PS rail.
- The VCC_DDR (1.8V) rail is generated by a MAX8632 switcher converting from the VCC12_PS rail. This controller also supplies the VTT0P9_DDR rail from an internal linear voltage regulator.
- The VCC1P05 rail is supplied by a Maxim* MAX8792 switcher converting from VCC5_PS.
- The VCC1P2 rail is supplied by a TPS74801DRC linear regulator converting from the VCC3P3_PS rail.
- The VCC1P8 rail is supplied by a TPS74801DRC linear regulator converting from the VCC3P3_PS rail.
- The VCCGFX rail is supplied by an Intersil* ISL8014 single phase switcher converting from the VCC5_PS rail. This regulator is configured to supply either 1.05V for Desktop processors or 0.89V for Mobile processors.
- The VCC3P3_STBY rail is supplied by an LT1764 linear converting from VCC5_PS_STBY.

Intel® Atom™ processor E600 series

The Intel® Atom™ processor E600 series CPU contains an embedded graphics controller. The graphics core is powered by the Vnn rail which is controlled by the VID bus just like the processor core. The processor has only one VID bus pinned out. This bus is multiplexed to control the IMVP-6 controllers for both the CPU core and the graphics core.

- CPU core rail (VCC_S) is supplied by a switching regulator converting from the V12_S rail and controlled by a Maxim* MAX8796 controller.
CPU Graphics core (VNN_S) is also supplied by a MAX8796 controller converting from the V12_S rail
- The V3P3_A rail is supplied by a TPS799 linear regulator converting from the V5_A rail
- The V3P3 rail is supplied by a single phase switcher using a TPS51117 converting from the 5V
- V3P3 is switched to V3P3_S with a TPS22922 Low RDS(ON) Load Switch
- The V1P8 rail is supplied by a TPS51116RGE switcher converting from V5_A or V12_S
- An AS1371 and an AS1361 respectively from Austria Micro* are used to create the V1P05V @ 400mA and the V1P5_S at 150mA
- An LM20124 switcher with integrated mosfets is used to create V1P05 converting from V3P3
- The SMC is an Altera* EPM570_100P

Operating With a Fixed Core or Graphics Core Voltage

The design engineers working on an embedded system will always try to create the least expensive, simplest solution that works. An obvious place to look at pruning complexity is the IMVP compliant power supply. The obvious question is can I use a fixed voltage instead of IMVP regulator? The answer is, with a lot of testing you might find a solution that works now, but the CPUs produced in the future batches might behave differently.

Generally, higher core voltages (CPU core or graphics core) enable higher performance and faster logic circuits, but if the voltage is too high it may damage or degrade the silicon and limit the lifespan of the CPU.
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Generally, lower core voltages reduce the energy requirements, and reduce the power that must be dissipated as heat, but if the voltage is too low, you run the risk of causing a logic failure that may cause the system to hang, reboot or blue screen.

If the core voltage is fixed it must be fixed at a voltage level high enough to enable the required performance, yet low enough that the part is not damaged and low enough that the CPU maximum operating temperature is not exceeded.

If a fixed operating voltage is tested, and found to be acceptable for a batch of CPUs, it is possible that parts produced in the future might require different voltages. Intel CPUs are programmed with the required operating voltages for each individual part during production testing. Intel can only guarantee the performance and lifetime of processors that are operated within the conditions specified by the datasheet.

Conclusion

This paper has presented some of the power supply requirements, and solutions that are suitable for Intel® Atom™ processor systems in embedded applications.

For requirements specific to individual processors or platforms refer to the appropriate processor datasheet, external design specification (EDS), or appropriate platform design guide (PDG).

In addition, to support and design collateral from Intel, use the resources of third party vendors when designing your embedded power supplies. They should be able to supply datasheets, reference schematics, reference PCB layouts, and application notes and assist you with the power supply design.
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Acronyms
CRB Customer Reference Board
ECG Embedded and Communications Group
IMVP Intel Mobile Voltage Positioning
SMC System Management Controller
PMIC Power Management Integrated Circuit
VID Voltage Identification
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