The Power Management IC for the Intel® Atom™ Processor E6xx Series and Intel® Platform Controller Hub EG20T

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Executive Summary

Time to market, cost, board size constraints, reliability and design capabilities are among the motivating factors in choosing Power Management IC versus a discrete solution. However, a discrete solution allows design optimization, offers higher power efficiency, flexibility and is easy to debug. Often, it is not possible to determine which choice will be better without understanding the details of design requirement.

This paper aims to discuss both the advantages and disadvantages of using Power Management IC versus a discrete solution on the Intel® Atom™ Processor E6xx series platform.

The Power Management ICs comprise mostly analog elements, for instance LDO and DC to DC voltage regulators, clock synthesis and digital state machines for power system and power sequencing control. They usually require a sophisticated process technology for fabricating the mixed analog and digital IC. Dialog Semiconductor* and Rohm Semiconductor* have years of experience developing power management solutions. They have offered Power Management IC solutions for Intel® Atom™ Processor E6xx series and various I/O hubs. (Dialog*- DA6011 and Rohm* - BD9591MWV /BD9594MWV). This paper will discuss the details of the Power Management IC covering the building blocks, features and vendors solution.

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Background

The Intel® Atom™ Processor E6xx is a new embedded System on a Chip (SoC), with the idea that it can serve as a high performance, ultra-low power and low cost single chip processor for applications such as deeply embedded IP media, networking, digital signage, and industrial control. It consists of a single low power IA CPU core, memory controller, 3D graphics, video decode and video encode engine, 2D display controller, SDVO and LVDS interfaces, Intel® High Definition Audio Controller, GPIOs, SMBUS, SPI interface connectivity to SPI flash, LPC, PCIe controller, RTC, 8254 timer and watchdog timer. The different sub-systems require different supply voltages and draw different amount of currents. While in operation, the power consumption of the device is the highest and power management should be designed as economically as possible. While on standby, the power consumption of the device should be reduced to the absolute minimum. Transition from standby to operation mode must be achieved as smoothly as possible, with no voltage or current spikes that could disrupt the operation of the device.

In designing an embedded system, power management is often a secondary consideration. Discrete components are initially selected for power management to give flexibility in development and debug. In later stage, these discrete components are integrated into single or dual ICs for power management. This saves space on the PCB, reduce Bill of Materials, simplify the PCB layout and achieve further power saving by intelligent switching, and reduction of power consumption by the power management system itself.

This article describes the solutions created during the course of engagement with Dialog Semiconductor* and ROHM Semiconductor* in designing the Power Management IC.

Solution

Today, modern integration technologies have brought about improvements to the power management IC. Dialog Semiconductor* and ROHM Semiconductor* have provided fully integrated power management ICs for the Intel® Atom™ Processor E6xx, Intel® Platform Controller Hub EG20T, DDR2 down devices (maximum of 8 loads of 1Gbit memory down device) and SPI flash. Both vendors have integrated Intel® Mobile Voltage Positioning – 6 (Intel®MVP-6) controllers, DC to DC converters, LDO regulators, Power FET, clock synthesizer and system management controller into one or two devices. The power management IC is scalable to the various companion IOHs, such as, the Intel® Platform Controller Hub EG20T, OKI Semiconductor* IOH, Realtek* IOH and STMicro* IOH. The integrated clock building block is
The Power Management IC for the Intel® Atom™ Processor E6xx Series and Intel® Platform Controller Hub EG20T
designed according to the CK505 clock synthesizer specification. The integrated system management controller manages the Intel® Atom™ Processor E6XX and Intel® Platform Controller Hub EG20T or other IOH during system power up, standby, reset and power down. The general concept of an integrated Power Management is shown in Figure 1.

**Figure 1: The General Power Management IC Block Diagram**

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**The Power Management IC Concept**

The Power Management IC is a highly integrated flexible system on chip solution for Intel® Atom™ Processor E6xx and I/O-hubs. It is a single or two chip solution to provide all power and clock supplies as well as system power management control. Figure 2 shows the key components in a Power Management IC.
Power Management Block

The basic components of a power management unit are linear voltage regulators, known as low-dropout (LDO) regulators, switching voltage regulators, known as DC-DC regulators and Intel® Mobile Voltage Positioning (IMVP)-6, known as IMVP-6 regulators.

An LDO regulator is ideal for supplying the PLL and analog blocks of an Intel® Atom™ Processor E6xx where low noise, low quiescent current and low drop out are essential.

Step down DC-DC regulator is usually used for supplying the I/O core supply voltage due to its high power efficiency. However, the quiescent current of DC-DC regulator can be 100 times higher than equivalent LDO regulator. The FET switches can be either fully integrated or externally.

IMVP-6 is usually used to regulator power to the CPU and Graphics cores inside the Intel® Atom™ Processor E6xx. It supports the real-time dynamic switching of the voltage and frequency between multiple performance modes, also known as Enhanced Intel® SpeedStep Technology. This technology allows the switching of the bus ratios, the variation of core operating voltage, and the variation of core processor speeds without resetting the system. With Enhanced Intel® SpeedStep Technology, there can be more than two modes...
of operation. That is, the processor requests IMVP-6 to provide more than two voltage levels depending on the power saving mode.

**System Power Management Controller Block**

The Power Management IC includes the Power System Management Controller block to manage the power management transitions of the Intel® Atom™ Processor E6xx and other I/O-Hubs. The block is designed for multi-voltage system power up and system reset. The block is always powered up first and then it manages the start sequence for other blocks inside the power management IC as well as other devices.

The block interfaces with the Intel® Atom™ Processor E6xx via the SLPMODE, SLPRDY_B, RSTRDY_B, RSTWARN and PWRMODE [2:0] signals to determine the power on, down, reset transition and via RSMRST_N, SLP_S5_N, SLP_S3_N, PWROK and CPU_RST_N, RESET_N signals to determine the system reset and S-states.

The RST_PLA_N, RST_PLB_N, RST_PLC_N, SLP_PLB_N, SLP_SLC_N and PWRGD signals are used to manage the power management of the Intel® Platform Controller Hub EG20T or other IOHs, DDR devices, power and reset buttons. The signals are shown in Figure 3.

The common system power sequences such as system power on and down, cold and warm reset, enter and exit Sleep S3 state, Wake-On-LAN and catastrophic shut-down are supported by the Power Management IC.
Figure 3: The Power Management IC Input & Output Control and Handshake signals
Clock Synthesis Block

The system clock generator provides timing for all components in the system except for the real time clock. Table 1 shows the implementation of clocks for the Intel® Atom™ Processor E6xx and Intel® Platform Controller Hub EG20T.

Table 1: Output Clock Features of PMIC

<table>
<thead>
<tr>
<th>Source</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Oscillator</td>
<td>25 MHz</td>
</tr>
<tr>
<td>Output Clocks</td>
<td></td>
</tr>
<tr>
<td>Intel® Atom™ Processor E6xx</td>
<td></td>
</tr>
<tr>
<td>Host Clock - BCLK</td>
<td>100Mhz Differential Signal</td>
</tr>
<tr>
<td>Host Clock – HPLL REFCLK</td>
<td>100Mhz Differential Signal</td>
</tr>
<tr>
<td>SDVO - DOT CLK</td>
<td>96Mhz Differential Signal</td>
</tr>
<tr>
<td>Reference Clock - REF CLK</td>
<td>14.318Mhz Single Ended</td>
</tr>
<tr>
<td>SRC Clock - PCIE CLK</td>
<td>100Mhz Differential Signal</td>
</tr>
<tr>
<td>Intel® Platform Controller Hub EG20T</td>
<td></td>
</tr>
<tr>
<td>PCIE CLK</td>
<td>100Mhz Differential Signal</td>
</tr>
<tr>
<td>SATA CLK</td>
<td>75Mhz Differential Signal</td>
</tr>
<tr>
<td>USB CLK</td>
<td>48Mhz Single Ended</td>
</tr>
<tr>
<td>SYSTEM CLK</td>
<td>25Mhz Single Ended</td>
</tr>
</tbody>
</table>

Others

Besides the power and clock, the Power Management IC vendors have incorporated other features like:

- Thermal Management
- Analog to Digital Converter (ADC)
- General Purpose I/O
The Power Management IC Goals

In choosing between discrete and Power Management ICs, typically, the tradeoff is between cost, design effort and performance.

At a minimum, the platform designer must evaluate the power and clock specification of the design; this includes assessing requirements of input and output voltage, current, power efficiency, supplies from the clock, noise tolerance and possibly other consideration. Even the Power Management IC solution is not exempted from careful planning.

Total Cost of Ownership

The cost covers the bill of material (BOM) cost in addition to platform designer labor fees, manufacturing & assembly cost, inventory holding cost, and issue debugging effort. Other potential costs can be from board re-spin due to poor design and quality issues.

Comparing the total cost between the two solutions, there is clearly a cost benefit to the Power Management IC as fewer components are used; design is simplified and allows less room for error. However, comparing the component BOM cost, there is no significant difference for both designs.

Design Effort

Clearly, the design effort using a fully integrated Power Management IC is less than discrete solutions. Sometimes, discrete design requires a more expert level of design capability; the platform designers must know which components are to be used and placed to achieve the desired layout and performance.

Component Board Area

The power management IC can provide >50% total component footprint saving including the traces and keep-out spaces. This will help a design fit into a small form factor platform.

Circuit Flexibility and Performance

The discrete solution allows the platform designer to change their solution with minimal schedule impact. For example, a power rail can be easily added or removed from the design. It also allows the platform designer to easily optimize the circuit, for example, shorten the power up sequence timing, and
optimize the FET selection for the specified operating voltage and current. Thus, the efficiency of a discrete solution can be better than Power Management IC in some cases.

The circuit performance is multifaceted and application dependent. For example, power efficiency is critical in battery operated design; temperature rise and size of the circuit can be the important specifications in thermal sensitive systems.

**Circuit Reliability**

The circuit failures can be due to

- Manufacturing assembly errors
- Incorrect design which lead to quality issues
- Component failures

Both discrete and power management IC are subject to all three categories above, but it is often the case where the power management IC vendors have carefully designed a solution which meets all Intel® Atom™ Processor E6xx and Intel® Platform Controller Hub EG20T design specification. They have validated the circuitry on the real platform and the learning has been documented in their datasheets, design guidelines and customer reference design guides.

The advantages and disadvantages of discrete versus Power Management IC are summarized in Table 2.

**Table 2: Advantages and disadvantages of discrete versus PMIC**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Comment</th>
<th>PMIC</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of platform design</td>
<td>Help to reduce power designer and layout designer labor fees</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Engineering sample/Si schedule</td>
<td>PMIC will impact the schedule as it is subject to reliability of new PMIC design</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Time to market</td>
<td>Most of the customers choose PMIC due to design simplicity. Customers will make fewer mistakes; require less technical knowledge regarding Power Management.</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Design effort</td>
<td>Schematic, PCB Layout and part</td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>
The Power Management IC for the Intel® Atom™ Processor E6xx Series and Intel® Platform Controller Hub EG20T

<table>
<thead>
<tr>
<th>Factors</th>
<th>Comment</th>
<th>PMIC</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debug capability</td>
<td>PMIC is a black box to engineering. Engineering support including on-site might be required if issues are found</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Design size</td>
<td>PMIC can offer smaller form factor and help reduce number of board layers</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Thermal advantages</td>
<td>Discrete offers optimization opportunity</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Circuit performance like output noise &amp; emissions</td>
<td>PMIC is better since it has integrated circuitry traces connecting all of the discrete components. Min the ESR &amp; ESL aspect.</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Efficiency of design</td>
<td>Discrete offers the better efficiency</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Platform scalability &amp; power optimization</td>
<td>Discrete allows flexibility to change the design/spec</td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

Dialog Semiconductor* Solution

The DA6011 is a single chip monolithic power management and clock companion IC for the Intel® Atom™ processor E6xx series. The single chip solution provides all power and clock supplies as well as system management control. It is designed to support platforms based on the Intel® Atom™ processor E6xx series, including the I/O hubs.

Power Management

Dialog Semiconductor’s new DA6011 uses a single supply voltage and provides low noise supplies to all CPU and I/O-Hub voltage domains with current management for the system DDR2 and boot SPI flash memory.

The DA6011 integrates 11 high performance low dropout (LDO) voltage regulators, which use Dialog’s patented Smart Mirror™ technology for very...
low quiescent current, and includes 3 pass devices for platform power distribution simplification.

Six DC-DC buck converters (three with external FETs and three with integrated FETs) provide current to the Intel® Atom™ Processor E6xx series platform’s multiple low voltage domains.

These buck converters supply the CPU and graphics cores and meet Intel® IMVP-6 specification. Furthermore, they power the system memories, the I/O-hub and further high current loads of the platform.

The power domain architecture has been carefully optimized to deliver enhanced power efficiency to the platform at the lowest power dissipation, thereby maximizing battery life and reducing thermal impact. The architecture also takes several I/O-hubs with its different power requirements into account.

**System Management Controller**

The integrated system management controller takes care of the complete platform start-up, state-transitioning and power-down procedures. It operates autonomously and reduces the overall system power consumption when entering stand-by or power down modes.

The flexible state-machine implementation is designed to control Intel® Atom™ Processor E6xx series based platforms including the Intel® Platform Control Hub EG20T, OKI Semiconductor* ML7223 / ML7213 and ST Microelectronics* STA2X11 I/O-hubs.

**Clock Supplies**

To manage the clock supplies four fractional division featured PLLs, two including spread spectrum capability are included in DA6011. The PLLs provide the clocks to the Intel® Atom™ Processor E6xx series as well as to the selected I/O hubs, further shrinking the component count. The reference clock for the PLLs is generated via a 14.31818MHz crystal oscillator.

**Auxiliary function**

An analogue to digital converter (ADC) with 10-bits resolution combined with an input multiplexer and track & hold circuitry has been implemented. Two inputs can be used to measure signals manually or automatically.
Operating conditions

Designed in accordance with AEC-Q100 specifications based requirements, the DA6011 operates between -40°C and +85°C to meet industrial and automotive temperature ranges. The die temperature and the output currents of each source will be monitored to ensure proper and safe operation.

Summary

Features:

- Power supplies & power management for Intel® Atom™ processor E6xx series plus I/O-hubs.
- Supports Intel® Platform Control Hub EG20T, ST Microelectronics* STA2X11, OKI* Semiconductor ML7223 and ML7213 I/O-Hubs.
- Programmable clock supplies dedicated to Intel® Atom™ processor E6xx series platforms with I/O-Hubs.
- Flexible, hardcoded SMC programmable via OTP.
- Automotive temperature range, meeting AEC-Q100 specifications.

Functions:

- 6 high efficient DC-DC buck converters.
  - 3 DC-DC converters with external FETs
  - 3 DC-DC converters with internal FETs
- 2 IMVP-6 compatible buck converters for Intel® Atom™ Processor E6xx.
- 11 high performance LDOs, which use Dialog’s patented Smart Mirror™ technology.
- 3 integrated pass devices for fully featured system with lowest possible BOM.
- A push-pull reference source/sink supporting up to 2GB DDR2 RAM termination even at the limits of the addresses.
- Autonomous, flexible state machine for complete system start-up and shut-down procedure
- 4 fractional divider PLLs including spread spectrum capability, designed for Intel® Atom™ Processor E6xx platforms
- 2 input 10-bits ADC for signal measurements
Applications:

- Vehicle command systems
- Telemetric devices
- Car navigation systems
- Mobile internet devices
- UMPCs
- High End PNDs
- Multimedia phones
- And many more

Packages:

- 169 VFBGA 11x11mm
- 0.8mm pitch

Key Differentiator:

- Monolithic single chip System on Chip solution
- Ultra low power, resulting in minimum thermal dissipation <1.4W maximum power drawn
- Highest efficiency in power saving modes as S3, S4/5 and SDP
- Supporting 2GB DDR2 with power and termination
- RTC power supply is included
- CPU and PCIe* clock including full feature spread spectrum
- Variable I/O-Hub system clock output voltage
- Full featured power push button

Rohm Semiconductor* Solution

Reliable 2 chip solution

ROHM Co. Ltd provides a two chips solution which is integrated Power Management IC and Clock Generator IC separated in order to avoid
noise/heat interference between PMIC and CGIC. Thus PMIC and CGIC can keep its integrity.

Not only its integrity, but also ease of design will be provided to the customers by using QFN packages. QFN packages is not required leading edge technology of board design such as stacked VIA or fine pattern dimension to route multiple of lines between the balls.

On top of that, output FETs are integrated into PMIC in order to reduce the external components count.

**Power Management IC**

The BD9591MWV/BD9594MWV is a single chip power management IC for the Intel® Atom™ processor E6xx series. The chip solution provides all power as well as system management control. It is designed to support platforms based on the Intel® Atom™ processor E6xx series, including the I/O-hubs.

The integrated system management controller takes care of the complete platform start-up, state-transitioning and power-down procedures.

The platform sequence is not required to be configured. It works as a stand-alone system automatically.

**Clock Generator IC**

The BU7335MWV is a single chip clock IC for the Intel® Atom™ processor E6xx series. The chip solution provides all the clocks. It is designed to support platforms based on the Intel® Atom™ processor E6xx series, including the I/O-hubs.

**BD9591MWV / BD9594MWV Device**

**Features**

- Power Management IC for Intel® Atom™ Processor E6xx Series, Intel® PCH EG20T, OKI semiconductor ML7213 and ML7223(V) and clock generator application
- The system regulator IC includes 1ch high efficiency DC/DC controller, 2ch IMVP-6 compatible high efficiency DC/DC regulators, 2ch high efficiency DC-DC regulators, 9ch LDOs and 6ch load switches.
- A simple system configuration can be achieved along with clock generator (BU7335MWV)
This device starts up by itself resulting in reduction of external component counts and the board space.

Controlling power regulation for each state (S4/S5, S3 and S0) results in a low power regulator.

**Power Planes Feature**

(Intel® Atom™ Processor E6xx Series)

- VCC_S for 1.1V Core Supply Voltage (0.75V-1.1V / 3.5A)
- VNN_S for 0.9V Supply Voltage (0.75V-1.1V / 1.6A)
- V0P9_S for DDR2 Termination (0.9V / 0.2A)
- V1P05 for 1.05V Core Suspend Rail (1.05V / 0.1A)
- V1P05_S for 1.05V Suspend Voltage (DMI, Fuses, DDR digital, DPLL, PCIe I/O, SDVO, DPLL, SDVO pads, HPLL (1.05V / 3.4A)
- V1P25_S for LVDS External Voltage Ref (1.25V / 0.007A)
- V1P5_S for 1.5V Sensors, Core PLL, Core Thermal Sensors Voltages (1.5V / 0.12A)
- V1P8_S for 1.8V Supply Voltage (LVDS Digital/Analog, DDR I/O, super filter regulators) (1.8V / 0.57A)
- V1P8 for 1.8V Supply Voltage (DDR SR) and DDR2 main power supply (1.8V / 2.4A)
- V3P3_S for 3.3V Supply Voltage (Legacy I/O, SDVO pads, RTC well) and SPI Flash (3.3V / 0.2A)
- V3P3 for 3.3V Supply Voltage (Suspend Power supply) (3.3V / 0.01A)

(Intel® Platform Controller Hub EG20T)

- VDDCORE_1.2V (VDDCORE_1.22V) for 1.2V digital VDD and PLL VDD (1.2V / 0.55A)
- IO_PLA_2.5V for 2.5V digital VDD (2.5V / 0.021A)
- IO_PLA_3.3V for 3.3V digital VDD (3.3V / 0.04A)
- IO_PLB_3.3V for 3.3V digital VDD, USB Analog VDD and USB ref VDD (3.3V / 0.28A)
- IO_PLC_3.3V for 3.3V digital VDD, PCIE analog VDD and SATA analog VDD (3.3V / 0.03A)
• USB_VDD_1.2V for PLL VDD and analog VDD (USB host and device) (1.2V / 0.14A)
• PCIE/SATA_1.2V for PLL VDD and analog VDD (PCIE and SATA) (1.2V / 0.4A)

Summary

Operating Condition:
• Operating Voltage Range: 4.5-5.5V (BD9591MWV), 8-19V (BD9594MWV)
• Operating Temperature Range: -40°C to +85°C (BD9591MWV/BD9594MWV)

Features:
• Complicated power ON/OFF sequence control (that up to now was performed by a microcontroller) is built in, facilitating IA platform design.
• System-optimized, high efficiency single external FET design contributes to greater miniaturization.

Applications:
• General Embedded Products (industrial PCs, medical equipment, POS systems, etc.)
• IP phones
• In-vehicle infotainment
• And many more

Packages:
• UQFN088V0100
BU7335MWV Device

Features
- Clock generator LSI for Intel® Atom™ Processor E600 Series, Intel® PCH EG20T and OKI semiconductor ML7213 and ML7223 I/O-Hubs.
- 5 integrated PLLs enable the generation of ALL required clocks (Intel CK505-compliant)
- Spread Spectrum function built-in for reduce EMI.
- Ideal for use with ROHM BD9591MWV/BD9594MWV PMIC.

Output clock Features
- 2 CPU Clocks (100MHz 0.8V Differential Output)
  - Supports spread spectrum modulation (-0.5% down spread)
- 5 PCI Express Clocks (100MHz 0.8V Differential Output)
  - Supports spread spectrum modulation (-0.5% down spread)
- 1 Selectable Clock
  - CPU Clocks (100MHz 0.8V Differential Output) or
  - PCI Express Clock: (100MHz 0.8V Differential Output)
- 1 DOT Clock (96MHz 0.8V Differential Output)
- 1 SATA Clock (75MHz/100MHz 0.8V Differential Output)
  - Supports spread spectrum modulation (-0.5% down spread)
- 1 USB Clock (48MHz 3.3V Single End Output)
- 1 25M Clock (25MHz 3.3V Single End Output)
- 1 MCLK Clock (12.288MHz 3.3V Single End Output)
- 1 REF0 Clock (14.318182MHz 3.3V Single End Output)

Summary

Operating Condition:
- Operating Voltage Range: 3.3V±5%
- Operating Temperature Range: -40°C to +85°C
Applications:

- General Embedded Products (industrial PCs, medical equipment, POS systems, etc.)
- IP phones
- In-vehicle infotainment
- And many more

Packages:

- UQFN64AV8080

Conclusion

A highly integrated power management IC for Intel® Atom™ Processor E6xx platform is presented in this paper. The Power Management Blocks, System Power Management Controller Block and Clock Synthesis Block are the key features of Power Management IC. Choosing between discrete solutions versus Power Management IC is often dependent on the design specifications.


Authors

Yew Chien Chern is a Platform Application Engineer with Embedded & Communications Group at Intel Corporation.
## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>BOM</td>
<td>Bill of Material</td>
</tr>
<tr>
<td>CLK</td>
<td>Clock</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>IMVP</td>
<td>Intel® Mobile Voltage Positioning</td>
</tr>
<tr>
<td>PCH</td>
<td>Intel® Platform Controller Hub EG20T</td>
</tr>
<tr>
<td>LDO</td>
<td>Low Dropout Regulator</td>
</tr>
<tr>
<td>Regulator</td>
<td>Power Management IC</td>
</tr>
<tr>
<td>PND</td>
<td>Portable Navigation Device</td>
</tr>
<tr>
<td>SOC</td>
<td>System-on-Chip</td>
</tr>
<tr>
<td>UMPC</td>
<td>Ultra-mobile Personal Computer</td>
</tr>
<tr>
<td>VR</td>
<td>Voltage Regulator</td>
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