

White Paper

M-WP012

A New Power Paradigm - DDR5 Memory Module Power Calculation

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Introduction

For many years, system designers have relied on current specifications that vendors provide for each DRAM part, known as IDD values. A vendor determines IDD values by using a standardized set of benchmarks that are meant to represent common high-level DRAM operations, such as reading one cache line of data from DRAM or refreshing data. State-of-the-art DRAM power models which designers currently use to perform DRAM power studies, and which are used by many popular simulators are still predominantly based on these IDD values.

Findings reveal DRAM power models are often highly inaccurate when compared with the power consumed by real DRAM chips. This is because existing DRAM power models:

1. Are based off of the worst-case power consumption of devices, as vendor specifications list the current consumed by the most power-hungry device sold
2. Do not capture variations in DRAM power consumption due to different data value patterns
3. Do not account for any variation across different devices or within a device.

Because existing DRAM power models do not capture these characteristics, it is often difficult for researchers to accurately identify sources of inefficiency within DRAM and evaluate the effectiveness of memory energy saving techniques.

Here are some observations about the DRAM power consumption that the current model cannot capture:

1. Across all IDD values that we use to measure, the current consumed by real DRAM modules varies from the current specified by the DRAM vendors
2. DRAM power consumption strongly depends on the data value that is read or written to it
3. There is significant structural variation where the same rails and rows across multiple DRAM modules from the same model consume more power than other rails or rows

On DIMM power management integrated circuit (PMIC):

A large change in DDR5 DRAM based dual in-line memory modules is the transfer of the PMIC (Power Management Integrated Circuit) on the DIMM itself rather than being on the motherboard. This helps calculate the power consumption of the DIMM with greater accuracy by tracking the output current values of the PMIC at the various operating modes of the memory module.

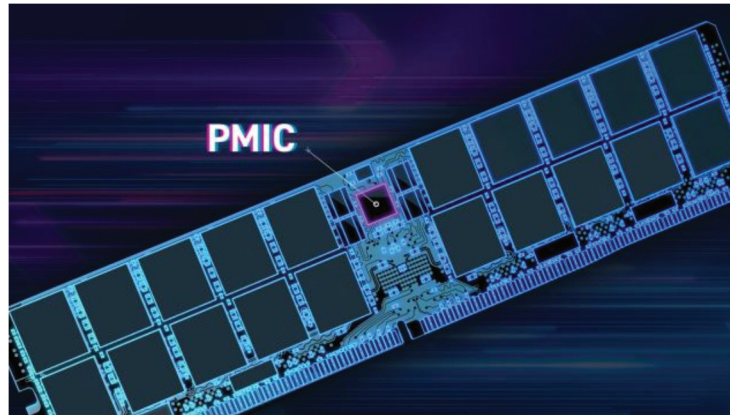


Figure 1: Shows a PMIC on board with the DDR5 memory module

A key point to note is the change in the power architecture between DDR4 and DDR5 based memory modules due to the shift in placement of the PMIC from the motherboard to the module level. Voltage regulation occurs on board in the module that provides better power distribution and stability while also enhancing the signal integrity of the memory module.

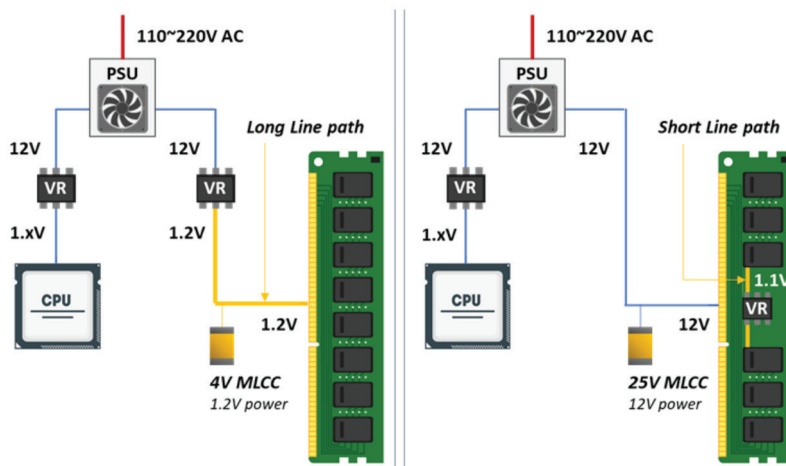


Figure 2: Shows the difference in the power architecture between DDR4 (left) and a DDR5 (right) based system

The diagram below shows the various input and output pins and rails to consider while modeling the system power using the PMIC I/O specification.

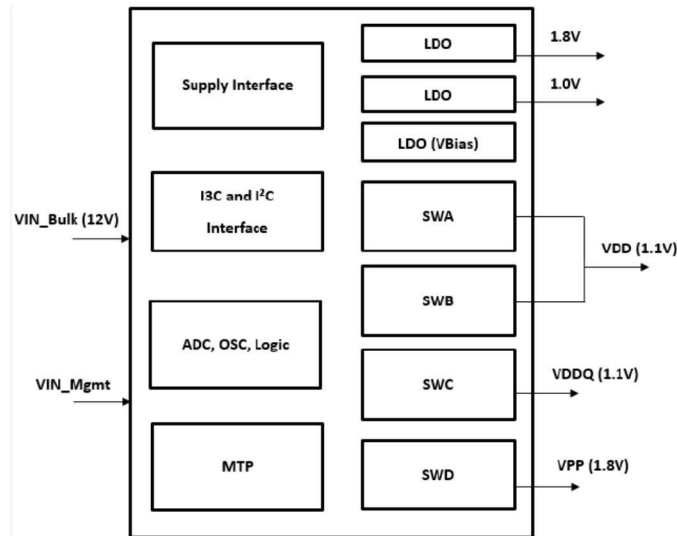


Figure 3: Shows the I/O operation of a DDR5 PMIC

To calculate the power consumption of a DDR5 memory module using PMIC values, various factors should be considered. Here is a general method to follow:

Determine the voltage and current ratings: Check the datasheet or specifications of the DDR5 memory module and identify the voltage and current ratings. Typically, DDR5 modules operate at a voltage of 1.1V, but it is essential to verify this information for a specific module.

Calculate the power consumption per rail: DDR5 memory modules consist of multiple rails. Calculate the power consumption per rails by multiplying the voltage with the current rating for each rails.

Power consumption per rails = Voltage (V) × Current (A)

Determine the number of rails: Find out the number of rails present in a DDR5 memory module. This information can be obtained from the module specifications or datasheet.

Calculate the total power consumption: Multiply the power consumption per rail by the number of rails to get the total power consumption of the DDR5 module.

Total power consumption = Power consumption per rail × Number of rails

Account for additional power overhead: In addition to the power consumption per rail, DDR5 modules typically have some power overhead due to circuitry, signaling, and other factors. This overhead can vary depending on the module's design and specifications. Check the datasheet or technical documentation for any specified overhead values and add them to the total power consumption.

Consider PMIC efficiency: The PMIC that supplies power to the DDR5 module may have an efficiency rating. Multiply the total power consumption by the reciprocal of the PMIC efficiency to account for any power loss.

Actual power consumption = Total power consumption / PMIC efficiency

Keep in mind that these steps provide a general approach to calculate power consumption using PMIC values for DDR5 memory modules. However, the specific power consumption characteristics may vary based on the module's design, operating conditions, and additional features. For accurate results, it is always recommended to refer the datasheet or technical documentation provided by the memory module manufacturer.

Taking a DDR5 RDIMM as an example:

To calculate the power consumption of a DDR5 RDIMM (Registered DIMM) memory module using PMIC (Power Management Integrated Circuit) current values, the following steps need to be considered:

Determine the voltage rail: Find the voltage rail supplied to the DDR5 RDIMM module. Common voltage rails for DDR5 memory modules include VDD, VDDQ, and VPP.

Obtain the PMIC current values: Refer to the datasheet or specifications of the PMIC to determine the current values for the specific voltage rail(s) powering the DDR5 RDIMM. The PMIC datasheet should provide details on the maximum or typical current values for each rail.

Calculate power consumption: Once the current values are gathered, the power consumption for each voltage rail can be calculated using the formula below:

Power (W) = Voltage (V) × Current (A)

For example, if the voltage rail VDD has a current value of 0.5A, and the voltage supplied is 1.2V, the power consumption would be:

Power (VDD) = 1.2V × 0.5A = 0.6W

Repeat this calculation for each voltage rail powering the DDR5 RDIMM.

Sum up power consumption: If there are multiple voltage rails, sum up the power consumption values for each rail to get the total power consumption of the DDR5 RDIMM memory module.

It is important to note that the power consumption calculated using PMIC current values will provide an estimation of the module's power consumption under normal operating conditions. However, actual power consumption can vary based on various factors such as module configuration, data transfer rates, and memory access patterns.

Power consumption during various operating modes:

To calculate the power consumption for each operating mode. Multiply the voltage by the current to obtain the power consumption in watts. Repeat this calculation for each relevant operating mode, such as active mode, idle mode, or standby mode.

Consider the different power states of the RDIMM module. DDR5 RDIMMs have multiple power states, including active, idle, and standby. Each state has its own power consumption level. Refer to the DDR5 RDIMM specifications to determine the power consumption for each state. Sum up the power consumption for each operating mode.

For example, if the voltage of the DDR5 RDIMM memory module is 1.2V and the PMIC current values are 50mA for the active power mode and 3mA for the standby power mode, the power consumption can be calculated as follows:

$$\text{Active Power Consumption} = 1.2\text{V} \times 50\text{mA} = 60\text{mW}$$

$$\text{Standby Power Consumption} = 1.2\text{V} \times 3\text{mA} = 3.6\text{mW}$$

Note that the power consumption will vary depending on the operating conditions and workload of the memory module. These values are typical values and should be used as a guideline.

Focus on maximum I/P current specifications for PMIC and correlate these values with each rail power consumption.

To calculate V_{in} with 100% efficiency:

| | I (in) = | I(out) | V(out) | V(input) | Efficiency |
|------|----------|--------|--------|----------|------------|
| PMIC | 0.135346 | 1.477 | 1.1 | 12 | 1 |

$$I(\text{in}) = (I(\text{out}) * V(\text{out})) / (V(\text{input}) * \text{Efficiency})$$

$$\text{Power} = I(\text{in}) * 12 = 1.62\text{W}$$

To calculate V_{in} with 90% efficiency:

| | I (in) = | I(out) | V(out) | V(input) | Efficiency |
|------|----------|--------|--------|----------|------------|
| PMIC | 0.17889 | 0.560 | 3.45 | 12 | 0.9 |

$$I(\text{in}) = (I(\text{out}) * V(\text{out})) / (V(\text{input}) * \text{Efficiency})$$

$$\text{Power} = I(\text{in}) * 12 = 2.14\text{W}$$

The same procedure and formula has to be used for each power rail in the DIMM. Following this, all the power consumed by the rails has to be added up to give an accurate representation of the total power consumed by the memory module for a particular mode of operating state.

The PMIC datasheet can be referred to for the I (out) and V (out) specifications for the various operating states.

Conclusion

At first glance at the DRAM integrated memory module data sheets, it is difficult to determine how much power each DDR5 DRAM will consume in a system environment. However, by understanding how a DDR SDRAM consumes power, it is possible to create a power model based on the PMIC values and the system usage conditions. A system designer can utilize this model to accurately approximate the power requirements of a DDR5 DRAM integrated memory module in a system environment. These results can be used to optimize the system power delivery and thermal budget to optimize performance versus cost of the system.

This model allows a system designer to experiment with various memory operational states to determine the impact on power consumption. This tool provides a method for estimating the power increase and for making system architecture and design decisions. By accurately estimating realistic power consumptions, the system designer is able to handle all system trade-offs to optimize the system for its determined use.



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