Leveraging Memory Technology to Cut Data Center Power Consumption

The significant role of leading-edge DRAM technology with regards to total power consumption and performance/Watt of server systems in a data center running virtualized environments

December 2010
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Shifting Paradigms

Within modern data centers, virtualization has become the means of choice when it comes to operating efficient server infrastructures for cloud and enterprise computing. On an individual system level, this translates into a massive increase of DRAM deployments per server. Hence the DRAM’s share in system power consumption and heat generation for non-persistent memory is much greater than has been known in the past. Leading-edge DRAM technology offering lower energy consumption and less heat dissipation per Gigabyte should deliver significant benefits at the system and data-center levels with regards to energy consumption for the computing system (regarded as primary energy consumption) and cooling (secondary energy consumption). Within this project we have analyzed the potential leverage of leading-edge memory technology in terms of the power savings for overall complete data center. We have selected two identical state of the art server systems with an identical configuration including major components such as power supply, CPU, fan and Hard Disk Drive (HDD) storage.

Summary of Results

Our measurements show that the use of leading-edge DRAM technology of a 30nm class will reduce the total power consumption of server systems in a data center running virtualized environments by almost 20% or 70W per system when compared to conventional 50nm class geometry at a deployment level of 48GB per CPU in a server. Direct IT power savings yield reduced UPS losses that are subject to the efficiency factor of the UPS system. We also learned that the temperature of the out coming airflow from server systems is about 1.5°C lower, which in turn can contribute to power savings of up to 60% in Computer Room Air Conditioning (CRAC) when server systems are populated with 30nm class DRAM. Another possible course of action would be the lifting of the chilled water temperature resulting in a significant reduction of the chillers’ power consumption if coupled with free cooling. Assuming a PUE of 2.0, calculations show that a data center investing in 1000 state of the art server systems while adopting 30nm class instead of 50nm class DRAM will save up to 23% in total energy consumption, or 170kW. This could save up to around €1million from the total cost of ownership,
assuming an operating lifetime of four years. At the same time, the data center’s CO₂ emissions will be reduced by 700 tons per year or 2800 tons over the lifetime of the server (typically assumed to be four years).

SPEC* measurements show that over all load levels the system with 30nm class modules have around 10% better performance, consume approximately 20% less power and deliver around 40% better performance/power compared to the one using 50nm class modules.

Set up

- Two Fujitsu PRIMERGY TX300 S6 servers, 2 socket platform with each
  - Two Intel Xeon L5640 6C/12T, 2.26GHz, 12MB
  - Eight HDDs (4x Seagate + 4x Fujitsu, each 73GB)
- Samsung registered DIMMs
  - Conventional DRAM system: 12 units of 8GB 1Gb based 56nm components, running at 1.5V = 96GB total deployment (Samsung Part number: M393B1G70EM1-CF8)
  - Leading-edge DRAM system: 12 units of 8GB 2Gb based 35nm components, running at 1.35V = 96GB total deployment (Samsung Part number: M393B1K70DH0-YH9)
- TUV Rheinland climate test chamber
  - Testing facility and equipment: all tests carried out by TUV Rheinland
  - The electrical power was measured using a reference class power meter providing a measurement inaccuracy of 0.02%. Temperatures were taken by calibrated PT100 sensors. The air flow was determined by a sensor installed in an air duct with defined dimensions.
- Microsoft Windows Server 2008 R2 Enterprise and Hyper-V role with activated power saving features of Windows Server 2008 R2, including 20 Clients as Virtual Machines

TUV Rheinland performed the tests in a climate chamber especially constructed to simulate a realistic data center environment. Figures 1a and 1b show the schematic setup and describe the sensors employed. The electrical power was measured using a reference class power meter providing a measurement inaccuracy of 0.02%. Temperatures were taken by calibrated PT100 sensors; the air flow was determined by a sensor tube installed in an air duct with defined dimensions.
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Figure 1a and 1b.: Experimental schematic and description of sensors

Figures 2a and 2b show the position of sensors and submit an impression of the overall climate chamber. Our target was to establish an environment similar to a data center on a smaller scale.

Figures 2a and 2b. Experimental installation at TUV Rheinland climate test chamber

Detailed Result Overview

The following diagrams depict the differences in power consumption and heat generation of both systems. These were tested with 20 VM clients in a logged-in state.

The test setup showed a 70W difference in power consumption between the two systems. At the same time the system working with 30nm class DRAM modules displayed 1.5°C lower air temperature flowing through the server system.

Figures 4a and 4b show samples of the measured quantities for power consumption and temperature. Both servers were fully loaded with virtual machines using about 96% of the physical memory. The servers were running constantly with minor amplitudes.

Using the latest DRAM technology delivers system-level energy savings as well as secondary savings in cooling and UPS losses
The temperature graph (figure 4b) shows to the left a temperature rise as the climate chamber establishes the desired server input temperature, reaching the target of 23°C at 18:22.00. For the data analysis, only data of stable conditions were used.

Figure 4a. Primary DRAM memory power consumption (Active Mode); Figure 4b. Heating effect on air flows (Active Mode).
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**Active mode:** all clients virtual machines are logged in and Memtest benchmark running

**Idle mode:** all clients virtual machines are turned off

In idle mode, reducing Memtest benchmark to a lower level of DRAM capacity per client showed that power consumption and heat dissipation do not differ significantly compared to active mode.

Fujitsu’s ServerView software delivered the respective power consumption shares of the servers’ components. The power composition, broken down by major consumer, is shown in the pie charts of figure 5a and 5b.

*Figure 5a and 5b. Power consumption of system components based on Fujitsu’s ServerView Application measuring the values of installed sensors at major hardware components in PRIMERGY systems*

The reduced overall system power consumption of the 30nm DRAM modules not only reduces the total operating costs of the system but requires less cooling for the system. In data centers with Computer Room Air Conditioning (CRAC), this may allow a smaller and lower-cost CRAC system, reduced runtimes or the use of less intensive operating modes. In the test climate chamber at TUV Rheinland, the exhaust air of the system with 30nm DRAM modules was around 1.5°C cooler than the air of the 50nm DRAM system.

In order to determine the impact of the hardware used, the DRAM modules were switched between the servers. Test results show similar values of the power consumption as shown in figure 6.
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Figure 6. Power consumption when DRAM modules switched between servers.

Figures 7a and 7b. Potential savings based on differences in DRAM power consumption and heat dissipation on system level.
The effect for the Data Center

While the savings per system may appear small, the overall savings for a larger environment like a data center with hundreds or thousands of servers are significant. With the following assumptions we calculated the energy consumption of a typical data center in terms of the number of server systems:

- PUE = 2
- Active Mode
- Product Life Cycle (PLC) = 4 years
- Cost of energy: 1 kWh = 0.175 Euro or 1.5 Euro per Watt per year
- Total cost saving [Euro] = power saving in data center in a year [W] x 4 [year] x 1.5 [Euro/(W*year)]
- The model includes secondary power savings resulting from up to 60% saving in CRAC (the equivalent of up to 6% of total data center power)
  - Secondary savings are related to lower system temperatures, evidenced by 1.5°C lower exhaust air temperature.
  - Reduced UPS losses

The model uses only the results tested in this experiment and the above assumptions. No other aspect is leveraged in the model. The data center savings are shown in figures 8a and 8b. The data was calculated with secondary savings of 60% in CRAC power and costs.

*Figures 8a and 8b. Potential savings in different scaling scenarios*
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**Figure 9. Typical Data center power consumption model for PUE = 2 taken as basis of the model for the calculation of power consumption**

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**SPECpower Test**

In practice, customers expect that any improvements introduced should deliver the same or better performance while saving power. We have verified this using SPECpower tests. SPECpower is able to show the performance per watt (efficiency) with various loads on the system, thereby covering the typical situation in actual data centers. These currently operate at around 20% load in a non-virtualized environment and up to 60% load within virtualized applications.

SPECpower_ssj2008 is the first industry-standard benchmark for measuring both the performance and the power consumption of servers.

“.. At a high level, the benchmark models a server application with a large number of users. Requests from these users will come in at random intervals (modeled with a negative exponential distribution), and processed by a finite set of threads on the server. The exponential distribution may result in Bursts of activity; during this time, requests may queue up while other requests are being processed. The system will continue processing transactions as long as there are requests in the queue. The actual implementation of this model is a bit more complicated. The data set is composed of several mostly-independent “warehouses”.”


In this experiment, the SPECpower_ssj2008 Benchmarking was performed at Fujitsu benchmark lab in Paderborn/Germany, which is a SPEC accepted test location. The test setup comprised Fujitsu PRIMERGY TX300 S6 servers, each featuring a two-socket platform and dual X5670 2.93GHz CPUs.

For this measurement we have included 12 Samsung M393B1K70BH1-CH9 8GB modules, built using 56nm/1.5V 2Gb components to increase the transparency of measurements and validity of data (used in Configuration C).

We needed to tackle the topic of performance in relation with memory ranks. Tests were performed using three different configurations, as described in figure 10. The illustrations in figures 11, 12 and 13 show the results measured with each configuration.

**Figure 10. DRAM configurations for SPECpower test.**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td># of DPC</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2Gb based 30nm</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2Gb based 50nm</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>1Gb based 50nm</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
</tbody>
</table>
Configuration A:
The same module configuration as in climate chamber test

<table>
<thead>
<tr>
<th>Type</th>
<th>8GB 4Rx4 PC3-8500R (56nm)</th>
<th>8GB 2Rx4 PC3L-10600R (35nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module No.</td>
<td>M393B1G70EM1-CF8 0948</td>
<td>M393B1K70DHD-YH6 1036</td>
</tr>
<tr>
<td>Base component</td>
<td>1Gb</td>
<td>2Gb</td>
</tr>
<tr>
<td>Voltage</td>
<td>1.6V</td>
<td>1.36V</td>
</tr>
<tr>
<td>Ranks</td>
<td>4Rx4</td>
<td>2Rx4</td>
</tr>
<tr>
<td>Freq. (MHz)</td>
<td>400</td>
<td>533</td>
</tr>
<tr>
<td>CAS Latency</td>
<td>6,0</td>
<td>7,0</td>
</tr>
<tr>
<td>RAS - CAS Delay</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>RAS Refrac</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Cycle Time (Clocks)</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Row Refresh (Clocks)</td>
<td>44</td>
<td>86</td>
</tr>
<tr>
<td>DIMMs per channel (DPC)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>[GB]</td>
<td>12 x 8GB</td>
<td>12 x 8GB</td>
</tr>
</tbody>
</table>

Figure 11a. System description for tests on configuration A.

![Graph showing efficiency and power consumption](image)

System with 30nm class configuration shows ~20% less power consumption, ~9% higher data throughput and ~40% better efficiency (performance/watt *). These results are valid over all load levels of both systems.

**Changing the number of DIMMs per channel from two to one, leads to a different rank configuration. Now the 1G base Module shows a comparable data throughput with 2Gb base modules**

Figure 11b (this page) and 11c (next page)
Observations for configuration A:

- 2 DIMMs per channel (DPC)
- The frequency of 50nm class DIMMs is reduced by system to 400MHz (800 Mbps) effectively due to total 8 ranks (2 DIMMs per channel x 4 ranks = 8 ranks);
- 30nm class DIMMs are reduced to 533MHz (1066 Mbps) effectively in order to keep the voltage at 1.35V; if LV DIMMs are to run at 1333MHz in 2DPC configurations, voltage has to be increased to 1.5V
- Performance is significantly lower for the 50nm class DIMMs having 8 ranks (two DIMMs per channel x four ranks). The CPU runs optimally at four ranks. Any deviations to this lead to a frequency adjustment.
- It shows that 8GB modules in a 2Gb base configuration are more efficient than 1G base 8GB RDIMMs.
- At the first Glance comparing modules with different frequency and voltage are unfair. But these combinations of modules are typical available parts in Market for corresponding technology node reflecting the yield of production. We have tested in below configuration also combinations that show reflect more different aspects of comparison.
**Configuration B**

Comparing 2Gb and 1Gb based DIMMs with 1 DIMM per channel configuration

Figure 12a. System description for tests on configuration B.

<table>
<thead>
<tr>
<th>Type</th>
<th>8GB 4Rx4 PC3-8500R (56nm)</th>
<th>8GB 2Rx4 PC3L-10600R (35nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module No.</td>
<td>M393B1G70EM1-CF8 0948</td>
<td>M393B1K70DH0-YH0 1036</td>
</tr>
<tr>
<td>base component</td>
<td>1Gb</td>
<td>2Gb</td>
</tr>
<tr>
<td>Voltage</td>
<td>1.5V</td>
<td>1.35V</td>
</tr>
<tr>
<td>Ranks</td>
<td>4Rx4</td>
<td>2Rx4</td>
</tr>
<tr>
<td>Freq. (MHz)</td>
<td>533</td>
<td>667</td>
</tr>
<tr>
<td>CAS Latency</td>
<td>7.0</td>
<td>9.0</td>
</tr>
<tr>
<td>RAS - CAS Delay</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>RAS Recharge</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Cycle Time (Clocks)</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Row Refresh (Clocks)</td>
<td>59</td>
<td>107</td>
</tr>
<tr>
<td>DIMMs per channel (DPC)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>[GB]</td>
<td>6 x 8GB</td>
<td>6 x 8GB</td>
</tr>
</tbody>
</table>

**Figure 12b.**

Changing the number of DIMMs per channel from 2 to 1, leads to a different rank configuration.

Now the 1Gb based Module shows a comparable data throughput with 2Gb based modules.

Observations for configuration B:

- Four-rank 1Gb based vs. two-rank 2Gb based modules and 1 DIMM per channel
- Four ranks per channel is the optimal configuration.
- The data throughput is slightly better but comparable for 1.35V 30nm modules due to higher frequency.
- The power saving for 30nm DIMMs is in range of 15% vs. the 50nm ones.
Configuration C
8GB DIMMs in 2Gb based configuration, different technology nodes in comparison

Figure 13a. System description for tests on configuration C.

<table>
<thead>
<tr>
<th>Type</th>
<th>8GB 2Rx4 PC3-10600R (??n)</th>
<th>8GB 2Rx4 PC3L-10600R (35n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module No.</td>
<td>M393B1K70BH1-CH9 0953</td>
<td>M393B1K70DH0-YH9 1036</td>
</tr>
<tr>
<td>base component</td>
<td>2Gb</td>
<td>2Gb</td>
</tr>
<tr>
<td>Voltage</td>
<td>1.5V</td>
<td>1.35V</td>
</tr>
<tr>
<td>Ranks</td>
<td>2Rx4</td>
<td>2Rx4</td>
</tr>
<tr>
<td>Freq. (MHz)</td>
<td>667</td>
<td>633</td>
</tr>
<tr>
<td>CAS Latency</td>
<td>9.0</td>
<td>7.0</td>
</tr>
<tr>
<td>RAS - CAS Delay</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>RAS Recharge</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Cycle Time (Clocks)</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>Row Refresh (Clocks)</td>
<td>107</td>
<td>86</td>
</tr>
<tr>
<td>DIMMs per channel (DPC)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>[GB]</td>
<td>12 x 8GB</td>
<td>12 x 8GB</td>
</tr>
</tbody>
</table>

Figure 13b. Comparing 2 ranks modules with different technology node
Observations for configuration C:

- Both DIMMs are two ranks*, and with 2 DIMMs per channel population in the system results in four ranks per channel configuration.
- Four ranks per channel is the optimal configuration.
- The system reduces the frequency for 1.35V modules in 35nm with 2 DPC configuration to 533MHz (1066 Mbps) to keep the low-voltage setting. If we would like to keep the frequency at 667MHz, the system would run the modules with 1.5V.
- The data throughput is slightly better for 1.5V 50nm modules, due to the higher operating frequency.
- The power saving for 30nm DIMMs is in the range of 12% compared to 50nm technology.
Conclusion

The test setup clearly demonstrates that the deployment of leading-edge DRAM technology in today’s virtualized data center environments can yield significant cost and CO₂ savings. At the point of Investment, replacing conventional 50nm class DRAM memory with 30nm class memory represents a comparatively easy means to either save on operating expenses or increase computing power in a given data center power envelope.

Current market and technology trends in the mid-range and high-end server segments suggest that the chosen setup with 48GB of DRAM memory per CPU is located towards the lower end of the typical deployment schemes. Particularly in physically dense rack and blade server environments, the upsides of using 30nm class based DRAM technology multiply thanks to their greatly superior characteristics of lower energy consumption and heat dissipation when compared to conventional DRAM technology.

To simulate the server loading efficiency in data centers we have performed SPECpower test. A typical data center shows 20-30% system loading and for a virtualized environment this value could reach up to 60%. Even for a different level of loading, the SPECpower test demonstrated that correct selection of memory has an important influence: currently, the 2Gb RDIMMs based on 30nm/1.35V chips have the best efficiency in terms of throughput versus power, across the full range of system loading.

Authors: Peyman Blumstengel & Thomas Arenz (Samsung Semiconductor Europe), Simon Jordan, Alfred Richter (TUV Rheinland), Susanne Brügelmann, Jürgen Häckel, Dieter Gottschling, Hansfried Block (Fujitsu), Frank Koch & Michael Korp (Microsoft), Gerold Würthmann, Ulrich Norf (Intel)

For comments and information on this white paper please contact:

Mr. Peyman Blumstengel peyman.b@samsung.com at Samsung Semiconductor Europe

Mr. Simon Jordan GreenIT@de.tuv.com at TUV Rheinland

Mr. Frank Koch Frankoch@microsoft.com at Microsoft

Mr. Michael Korp mkorp@microsoft.com at Microsoft Technology Center

Mr. Dieter Gottschling dieter.gottschling@ts.fujitsu.com at Fujitsu

Mr. Hansfried Block Hansfried.Block@ts.fujitsu.com at Fujitsu Lab, especially on SPECpower results

Mr. Gerold Würthmann Gerold.Wuerthmann@intel.com at INTEL EMEA
Room for Notes
Abbreviations and references used in this paper:

**SPEC®** and the benchmark name **SPECpower®** are registered trademarks of the Standard Performance Evaluation Corporation. [http://www.spec.org](http://www.spec.org)

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**CRAC:** Computer Room Air Conditioning is part of cooling system; refer to figure 9 for the model used

**DPC:** DIMM per Channel, number DRAM DIMMs modules populated into each available CPU Channel. In this set up the CPUs each have three channels for memory

**PUE:** Power Usage Efficiency, a key performance indicator of a data center in terms of power consumption efficiency for IT. It is calculated as the ratio of total data-center power consumption to IT power consumption.

**Rank:** memory rank is a specific memory area of 72 bits wide for RDIMMs that can be addressed by the CPU at one time.

8GB module based on 1Gb comprises 72 components. Each 18 units of DRAM components in x4 organization build a data width of 72 leading to four ranks.

In other words, each separate area of Memory discretely accessible with width of 72 bits is one rank.

**UPS:** Uninterruptable Power Supply

**Memtest:** MemTest is a RAM tester that runs under Windows. It verifies that a computer can reliably store and retrieve data from memory. [http://hcidesign.com(memtest)](http://hcidesign.com/memtest)

**CO₂ Emission and calculations:** CO₂ emissions calculated on basis of the average emissions factor per kWh for Germany 2009: 575g/kWh

[http://www.umweltbundesamt.de/energie/archiv/co2-strommix.pdf](http://www.umweltbundesamt.de/energie/archiv/co2-strommix.pdf)

**Modes of operation**

**Active mode:** all clients virtual machines are logged in and Memtest benchmark running

**Idle mode:** all client virtual machines are turned off
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History of revisions:

2.0:

- released on 30 November 2010, final and first publishing version after consolidation of input from all parties

2.1:

- revised Logo for Microsoft Technology Center
- revised the graph sizes
- Correcting few comments to be more specific
White paper: Leveraging memory technology to cut data center power consumption

About the companies involved (in alphabetical order):

About Fujitsu

Fujitsu is a leading provider of ICT-based business solutions for the global marketplace. With approximately 170,000 employees supporting customers in 70 countries, Fujitsu combines a worldwide corps of systems and services experts with highly reliable computing and communications products and advanced microelectronics to deliver added value to customers. Headquartered in Tokyo, Fujitsu Limited (TSE:6702) reported consolidated revenues of 4.6 trillion yen (US$50 billion) for the fiscal year ended March 31, 2010. For more information, please see: www.fujitsu.com

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Microsoft Technology Center (MTC)

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TÜV Rheinland

TÜV Rheinland is a leading group for the provision of technical services worldwide. It has over 490 locations in 61 countries on all five continents. With a workforce of 13,850, it achieves a turnover of approx. € 1.2 billion a year. The guiding principle in the Group is sustainable development of safety and quality standards. The motivating factor for TÜV Rheinland employees is the conviction that without technical progress, society and industry cannot grow. For this very reason, using technical innovations, products and equipment in a safe, responsible manner is of decisive importance. TÜV Rheinland has been a member of the Global Compact of the UN since 2006. TÜV Rheinland is 140 years old and its headquarters are in Cologne.


TÜV Rheinland Energie und Umwelt GmbH