“O.K. Google: How do I power a Data Center?”

“Ok Google: How do I power a Data Center?”

Claude Shannon started it all when he wrote “A Mathematical Theory of Communication” in 1948 in which he reduced the communication of information to 1s and 0s, essentially binary digits. That theory led to the ability to transmit data without error in the noise-filled environment of the real world. Shannon would have been 100 years old on April 30, 2016.

Moving 68 years into the future (I have been around for almost 67 years, so that’s a long time!), the Google announcement regarding that they and Rackspace are working on a new server design, the Zaius POWER9 Server, which will unseat Intel’s x86 processor incumbent and replace it with IBM’s new POWER9 processor (Although there are some very good new 48V direct conversion designs geared toward Intel processors as well as you will see later in this article by ST Microelectronics and Intersil to name a couple of power players.), have rocked the Data Center world. Power efficiency is the main thrust now so Google is even looking further into the future at the possible use of ARM-based processors to help save even more energy. Server architecture design will be re-vamped as well.

In addition, Google joined Facebook’s Open Compute Project and immediately proposed a new design to help cloud data centers lower their enormous energy bills. A new rack design will have 48V delivered directly to the servers to replace the 12V now being used by most servers. Google claimed that electrical conversion losses will be reduced by 30%.

So 48V would be delivered to the motherboard and further converted down to 1V or below to power the processor as close to that IC as possible---Oh yes---and with no noise which could contribute to processor errors.

Rick Merritt commented on the importance of this effort in a recent EETimes article entitled Google
Preps for IBM, ARM Shift.

Before we get into the power management solutions for the Server, let’s first take a look at what a Data Center looks like and the challenges that need to be overcome with fast-growing Internet usage led by the coming of 5G and the Internet of Things as well as Cloud growth in the data center adding tens of MegaWatts and more to each data center.

The Google Data Center

Let’s first look inside one of Google’s campus network rooms, routers and switches that enable the data centers to communicate with each other. See Figure 1.

![Figure 1: There are a myriad of fiber optic networks connecting Google Data Center sites together running at speeds that are an amazing 200,000 times faster than your home Internet connection. The fiber cables run along the yellow cable trays which can be seen near the ceiling in this image. (Image courtesy of Google)](image)

Cooling the heat in the Data Center

When we look behind the server aisle, we will find a not-too-glamorous array of hundreds of fans that remove the hot air from the server racks into a cooling unit to be recirculated. See Figure 2.
Figure 2: The fans can be seen highlighted in an eerie green alien glow from lights, which are the server status LEDs reflecting from the front of Google’s servers. (Image courtesy of Google)

For Gawd's sake, git the water, Gunga Din!

Huge storage tanks hold up to 240,000 gallons (900,000 liters) of water to cool the waste heat in a Data Center. See Figure 3.
Many other data centers use chillers or air conditioning units to cool the racks down. This technique, according to Google, uses a 30-70% overhead in energy usage. Google’s data center solution is to use water as an energy-efficient way to cool as an alternative.

They have designed custom cooling systems for their server racks called “Hot Huts”. These systems serve as temporary storage for the hot air that leaves the servers as they seal it away from the rest of the data center floor. There are fans atop each Hot Hut unit which will extract the hot air from behind the servers through water-cooled coils. The chilled air leaving the Hot Hut returns to the ambient air in the data center, where the servers can pull the chilled air in to cool them down in this efficient cycle. See Figure 4.
Figure 4: Plastic curtains hang in a network room inside Google’s Council Bluffs data center. Here they serve up cold air through the floor, and the clear plastic barriers help keep the cold air in while keeping hot air out. (Image courtesy of Google)

Evaporative cooling

Evaporative cooling works well in the cooling towers. As the hot water from the data center flows down the towers through a material that speeds its evaporation, some of the water will turn to vapor. A fan lifts this vapor which removes the excess heat in the process. The tower then can return the cooled water back into the data center.

In Google’s Data Center facility in Hamina, Finland sea water is used to cool without chillers. They chose this location for its cold climate and its location on the Gulf of Finland. The cooling system that was designed, pumps cold water from the sea to the facility, transfers heat from their operations to the sea water through a heat exchanger, and then cools that water before returning it to the gulf. This efficient method provides all of the needed cooling year round without the need to install any mechanical chillers. See Figure 5.
Figure 5: Server floors such as these require a huge amount of space and efficient power to run the full family of Google products for the world. In Hamina, Finland, Google chose to renovate an old paper mill to take advantage of the building’s infrastructure and its proximity to the Gulf of Finland's cooling waters. (Image courtesy of Google)

In addition, to better conserve water, two data centers are powered with 100% recycled water, and capture rain water to cool a third. This idea is pretty simple: instead of using potable (or drinking) water for cooling, they use non-drinkable sources of water and clean it just enough so it can be used for cooling.

Hovering above the floor in Council Bluffs, Iowa, the sheer size of a data center can be viewed in Figure 6. This space seen above the servers is a prime space for the Power distribution system whether it be AC or 400V. (See my EDN article on 400V in the Data Center.)
Now this brings us to the tech view for our power solution portion of this article.

**The new Power Solution for efficiency in Data Centers**

Now that we’ve seen what a Data Center is and the incredible amount of wasted heat from relatively small inefficiencies in a non-perfect semiconductor integrated circuit multiplied by an unbelievable multi-million times, let’s take a look some power management solutions which will amount to what Google claims will be a 30% improvement in electrical conversion losses.

Stephan Ohr, Consultant and Semiconductor Industry Analyst had some great comments in his EETimes article entitled *The Quest for Server Power Efficiency* just before APEC 2016.

At DesignCon 2016 there was a [DesignCon 2016 Panel with Google, Intel, Linear Technology, Intersil and Vicor](#) as panelists and it was here that we heard Google’s desire for 48-volt motherboards to cut wasted power in data center servers. Power efficiency in datacenters is estimated to be ~84%.

First let’s look at the typical main power sources and backup capabilities needed in a viable Data Center.

In a typical data center power enters the building via one or two separate grid sectors operated by the local power company. Redundancy is critical to the operation of a Data Center because failure in not an option here.

Many times the data center has diesel generators that can produce megawatts of power, which includes extra power to cover the data center’s electricity demand in an emergency.

Typically the local utility company and the diesel generators deliver electricity with a voltage of 20 kilovolts (kV) or so, that is then converted to 220 or 380 volts AC.

Within the data center, usually back-up batteries can power the Data Center for 15 minutes or so in the event of a power loss. This gives the diesel generators time to start up and get to power levels to run the facility.
A large UPS is also a part of the Data center power scheme. It can run on AC current and can supply tens of kilowatts at 480 volts. As the UPS draws AC power, it's converting some of that energy to stored DC power in the event of a power outage. It compensates for voltage and frequency fluctuations to protect sensitive processors and other electronic systems.

A redundantly designed power supply system is essential the data center. This will enable repairs to be performed on one network, without having to turn off servers, databases, or electrical equipment.

Today’s servers typically use 12V power supplies with efficiency levels in the 80% region mostly affected by the processor’s high power demands. See Figure 7. Some power designs and architectures for conventional regulators can get into the high 90’s percentile for efficiency, but this is still not enough. We now need to bring the power as close to the processor as possible as well as eliminate the multiple transformer losses in the power system chain today. The 12V motherboards in today’s servers are at least a 20 year-old technology. Somethings got to give! There is too much wasted energy in the Data Centers with the processor pushing the envelope in multicore architectures with ever-increasing speeds leading to higher power needs and more energy losses. Crank up those air conditioners.

Enter Google’s 48VDC architecture to the motherboard

Enter Google’s 48VDC architecture to the motherboard

We have seen Telecom using 48V for quite a while, so the idea is not a new one in that arena, but for Data Centers it is a new paradigm. Advantages abound for energy savings in the Data Center with lower I^2R rack losses and the use of one less transformer conversion loss as well.

There are, of course, new challenges that raise their ugly head, but these are not insurmountable. What do we do about light load efficiencies? How about 48V noise isolation and coupling? Why 48V and not 380V?

Let’s take a look at some of the really innovative solutions by top power vendors that solve these problems and answer these questions.
**Vicor solutions**

I still consider Vicor solutions as the number one best design architecture for 48V for many reasons. First, they have been working closely with Google on the 48V solution as well as the 380V transmission across the data center rafters for quite a while. Secondly, they have been supplying 48V power for FPGAs and DSPs for more than ten years with a wealth of motherboard expertise gained during that time. Third, they have one of the best thermal architectures I have seen in the industry with their innovative CHiP package thermal design (See my article on EDN two years ago that discussed the benefits of this design as well as the usage in a 380V Data Center transmission design entitled *Vicor Corporation CHiP bus converter modules*. Vicor was on to this structured architecture pretty early on in 2014.

Robert Gendron, VP of Marketing and Business Development gave us an overview of Vicor’s Data Center solution. In late 2013 Vicor had commented that Data Center designers’ and suppliers’ major cost concern is the power needed to run all the electronics; servers, switches, storage. Why is power efficiency so critical to Data Center operations? Because Datacenters have to pay for it twice!

1. As an input from a utility provider and/or the on-going cost of harvesting it from the environment themselves using [green technologies](#).
2. As an output from their equipment, the thermal waste of their operations (the *inefficiencies* of their electronics) must be removed from the equipment. Sometimes this can be reclaimed but not without the added cost of additional equipment.

Vicor was involved in a key panel discussion at DesignCon this year regarding 48V Servers. See Rick Merritt’s article on EETimes on this topic entitled *Google, Intel Prep 48V Servers*

A few of the panelists discussed challenges associated with locating regulators physically close to processors, Robert Gendron, Vicor’s VP marketing and business development highlighted what has already been achieved by Vicor, such as “using a 3D package suitable for placing near a processor socket”.

Vicor engineers are working to move the regulators even closer to the processor as he commented that, “a future version will use an even denser package that could be placed under the socket”.

Among the esteemed panelists were Neil O’Sullivan, a power group manager at Google and David Figueroa, director of enterprise power solutions at Intel.

There are certainly many challenges still to be addressed (See Figure 8.), but Vicor has already demonstrated some very creative and viable solutions. (See Figure 9)
The company promotes 48V for the rest of the design as well, not just for the Processor. A GPU, an ASIC, or DDR can also use 50A to 400A factorized power designs that use scalable PRM/VTM
components as well as PI3020 Digital Controller as seen in Figure 8. Digital power solutions like this are essential to the performance needed in a continuously adaptable power design to handle these heavy loads requiring fast response from the power supply as well as quick changes to light load conditions with an adaptable supply that can switch over to a different architectural mode to keep the efficiency high at light loads.

Zero Voltage Switching (ZVS)/Zero Current Switching (ZCS) buck regulators are also part of Vicor’s portfolio to provide rail support for lower current rails as well in the server.

Vicor’s 100A+ VTM IC with 200A turbo mode, is just what a server processor needs to replace multiple conventional DRMOS and inductor stages in a multiphase design (See Figure 11). It has a unique ZVS/ZCS resonant Sine Amplitude Converter topology, a highly integrated 3D package and operates at 1.5 MHz. There is no need to oversize the power design since this IC has its own turbo mode that can provide 2x current delivery for up to a 10 ms period. See Figure 10.

Figure 10: Here is a Vicor solution for high density functionality in a small package supplying all the needs of the processor. (Image courtesy of Vicor)
Figure 11: A conventional Multiphase design architecture is shown here. Vicor’s 48V direct to CPU reduces valuable real estate footprint near the CPU by more than 50% with no loss in performance since the PRM and Digital controller can be placed in non-critical board-edge regions. This also helps simplify CPU I/O routing and the low noise of the VTM alleviates concern of having any noise near CPU or data lines. (Image courtesy of Vicor)

What about efficiency? Well, the 48V Direct to CPU performance matches that of the 12V to 1V conventional multiphase architecture. Adding a 48V to 12V stage converter to a conventional multiphase architecture will only lower the power supply overall performance.

So, in total, 48V allows less cabling, crowding, cost, weight, I²R losses and Energy Storage Volume. This equates to a 16X reduction in power losses and a 4X reduction in capacitor volume.

Finally, let’s take a quick look at radiated noise in a Conventional Multiphase design vs. Vicor’s 48V Direct to CPU design using an x-y near-field scan test which shows a big difference in VTM performance over multiphase. See Figure 12.
A really close second great solution to Vicor's architecture is an innovative ST Microelectronics solution.

Paolo Sandri, Director of Marketing, IPG Industrial and Power Conversion, revealed at APEC 2016 that ST has a unique and fully isolated, resonant, single-stage direct conversion from 48V straight to the CPU/DD/ASIC/POL, in full compliance to Intel VR13 and VR12.5 specifications (no waivers needed from Intel), and a fully scalable solution able to manage up to 6 interleaved cells with dynamic cell shedding and pulse skipping. Their design team claims to achieve the lowest possible noise harmonic contents and optimum signal integrity (as a result of resonant operations with Zero Current and Zero Voltage switching (ZCS/ZVS) on both the primary and secondary side) which they state is industry leading.

Designers have implemented a really nice secondary side waveform, unlike the traditional square wave with its hard edges and the ringing and harmonic content baggage that it brings. They have designed a clever semi-sinusoid waveform, and that along with ZVS/ZCS ensures very low noise and the capability to be as close to the processor as possible without interference effects.

And remember that this architecture is readily adaptable and extendable to the next possible future step of efficiency improvement in the Data Center being discussed: that of 400V Direct Conversion bus to the processor.
STMicroelectronics’ 48V to 0.5-12V architecture is composed of their STRG02, a single-wire controlled synchronous rectifier with capability for ZCS/ZVS. They also have a full-bridge driver, STRG04, with programmable predictive control for zero voltage operations in constant phase shift control. And finally, their STRG06, is a Multiphase Resonant Constant On-Time Digital Controller that can support up to six interleaved converters (automatically turned on/off by load request) voltages between 0.5V to 12V. See Figure 13.

![Figure 13: STMicroelectronics' Isolated 48V to 0.5V-12V System Architecture. This architecture is actually a kind of hybrid: A resonant isolation input side along with a current doubler at the load. (Image courtesy of STMicroelectronics)](image)

This solution has a power density of 160W/in² and what I consider critical for Data Center applications, a Digital Power capability for adaptable control. For that, the system employs a PMBus for telemetry and Auto-Tuning.

Their new resonant topology allows Energy Proportional Management using Pskip and Dynamic Cell Management. The architecture is fully scalable (a very nice feature of this design) so that the converters can be paralleled and interleaved according to the load demand. They have Variable Frequency control in Continuous Current Mode (CCM) and Discontinuous Conduction Mode (DCM).

Another nice feature is the capability of instantaneous turn-on of the resonant converters when the load increases.
STMicroelectronics designers have carefully thought out this versatile solution which will be a key element in improving the Data Center efficiency going forward.

They also have a very nice reference design compliant to Intel VR13. See Figure 14.

![Figure 14: STMicroelectronics Intel VR13, 165W CPU Power delivery reference design. There are 4 cells in this design with 93% peak efficiency. (Image courtesy of STMicroelectronics)](image)

There are other reference prototype boards for 54V to 12V@500W and 54V to 3.3V@150W and a 54V to 1.21V@50W with 93.8% peak efficiency that may suit the Data Center in other areas. These are nice for designers to get to market quicker with a robust design due to the accessibility of Gerber files as well.

**CUI design and software support**

CUI Inc. takes a decided power approach for the Data Center that closely ties in Software Defined Power, what I have always considered a key element in power for a Data Center. When I was at APEC this year, I met with Mark Adams from CUI as they announced a limited exclusivity agreement for hardware development with Virtual Power Systems (VPS), a Software Defined Power® company. The two companies will partner to set a new standard for an efficient power infrastructure for data centers.
CUI plans to design, manufacture, and distribute the hardware component of the ICE (Intelligent Control of Energy) system which will employ the VPS solution. The ICE Block hardware is managed and controlled through the ICE Platform, a tightly integrated suite of software developed by VPS. VPS claims that the ICE Block will enable data center operators to double power and server utilization, reduce costs, and greatly improve availability.

This partnership is important because it is the first step in creating a larger Software Defined Power ecosystem, from board level to system level, ultimately creating a more intelligent, more efficient data center infrastructure.

The first ICE Block is under development now, with initial prototype installs coming later in 2016.
The teams feel that in an existing data center, they envision up to a 15-25% reduction in power cost coupled with the avoidance of 40-60% of conventional capex investment with the combined ICE system. Another key advantage of this new infrastructure is that it will enable data centers to continue their aggressive growth paths via a solution that can be installed and initialized in just days vs. the months required with traditional approaches. Data center operators can immediately experience significant improvements in operational flexibility, utilization, and management.

I chose Software Defined Power as one of the Hot Technologies going into 2016 in my EDN article "Software-defined power brings to bear critical need in modern power systems."

CUI understands Software Defined Power very well. See Mark Adams’ article on EDN entitled "Realizing the potential of software defined power."

Also, see the Digital Power section at the end of this article. **Maxim Integrated solution**

**Maxim Integrated solution**

Today’s Data Centers use about 2% of total global energy usage and by the year 2020, it is projected that just U.S. Data Centers will consume a whopping 140 Billion kW-hours. Of this power, it is estimated that the CPU and DRAM memory consume around 80% of the total server power at peak load, and this power need is increasing in future designs.

Maxim Integrated saw an opportunity to provide a needed solution for increasing the efficiency of a 48V to Point of Load (PoL) regulator.

*The existing 12V solution architecture for the Server Motherboard*

The power hungry CPU and Memory in present legacy Data Center Mother Board Power designs uses 12V to PoL DC/DC voltage regulators in a multiphase configuration and is 20+ years old. See Figure 17.
Maxim Integrated’s 48V solution uses six Direct Conversion from 48V to PoL DC/DC Voltage Regulators to power the hungry CPU and Memory. They also have existing 12V to PoL DC/DC Voltage Regulators for the 12V intermediate bus, storage drives and other various lower power rails still being used in the system. See Figure 18.
Maxim’s 48V Solution

- New 48V to PoL DC/DC Voltage Regulators
  - High power CPU & Memory
  - 6 direct 48V conversion VRs
- Existing 12V to PoL DC/DC Voltage Regulators
  - Intermediate 12V voltage bus
  - Lower power rails & storage

Figure 18: Maxim Integrated 48V Direct to PoL Solution (Image courtesy of Maxim Integrated)

The new architecture brings with it many efficiency benefits like 30% lower conversion losses, 16x less power distribution losses due to I^2R in connectors, cables and boards. Plus 48V is a well-documented and tried-and-true system used in Telecom Central Offices for many, many years. See Figure 19.
Linear Technology discrete solution

Linear Technology has released isolated power controllers, such as the LTC3765/3766 forward converter chipset, which allows designers the choice to implement a reliable and cost effective discrete / embedded solution for a 48V input system. See Figure 20.
Cloud computing and big data are driving massive investments and power usage in server and networking infrastructure. With their large power footprints, cooling costs at data centers can easily exceed 50% of the total operating costs. There is an acute need for improved power efficiency to enable a greener, more cost effective solution to the scaling needs of the cloud. The latest trend in meeting this goal is eliminating conversion steps in the power management chain. By delivering power to the processor from a 48V backplane, it eliminates the 12V intermediate step. This increase in voltage at the backplane from 12V to 48V reduces the distribution losses by 16x.
Intersil’s Director of Infrastructure Power, Chance Dunlap, gave us an account of their efforts in the Data Center:

To meet this challenge, Intersil’s ISL6388 digital PWM controller solution was designed to provide regulation and control for Intel server CPUs and works with the Vicor power stages for VR12 and VR12.5 designs (both Core and Memory) to provide the 48V to 1.xV conversion. The buffered compensation signal allows external power stages (Vicor PI3751-02 “PRM” and VTM48Kp020x “VTM”) to be regulated using the ISL6388 control loop. This provides for best-in-class control response from Intersil in responding to commands and load requirements from the Intel CPUs.

Intersil has been shipping these 48V to POL single-stage solutions for VR12.5 and VR12 servers in data centers for the past several years. This extends Intersil’s long history in multi-phase controllers in server applications. With a strong focus on server efficiency and power usage effectiveness (PUE) for hyperscale data centers, Intersil is working closely with industry leaders to standardize on a 48V rack standard and reduce the global cloud electricity footprint. Intersil’s advanced DC/DC converter technology enables data center equipment to improve low transient performance resulting in power savings that multiply over each line card. In fact, Intersil is one of very few companies with the ability to provide customers with real-time information about the power usage of their systems, enabling a level of optimization unprecedented in infrastructure applications.
Digital Power architectures are essential to the Data Center. With digitally enabled, configurable and fully programmable power controllers, data center power solutions get flexibility, efficiency and integration to meet dynamic system needs. Fast adaptable reaction to changing load conditions will make big improvements in Data Center efficiency. With powerful, high speed processors needing peak power at varying intervals, only Digital Power will be able to respond quickly to high current needs on-the-fly.

Digital power devices support a plethora of power topologies and thus are able to provide precise waveform control by using high-resolution phase, frequency and duty cycle control algorithms.

A Digital Power system could control the power distribution to every server in the rack and will have the capability to monitor and report on the operations of each server blade in that rack. The overall server supply on-time and efficiency can be improved by implementing Digital Power in a server power architecture.

We have seen CUI recently align itself with VPS for a complete Data Center Power Management solution including software. Now let’s look at a few other software solutions that combine the best of hardware and software for Power solutions in the Data Center.

First, we have Eaton’s recent introduction of Intelligent Power Manager™ software version 1.52, which can be integrated with the VMware vRealize® Operations™ platform. This integration allows viewing and managing power and equipment, like Uninterruptible Power Systems (UPSs) and Power Distribution Units (PDUs), with analytics for power capacity planning and workload placement.

This system enables predictive analytics capabilities and smart alerts to implement preventative maintenance or repair services on their power systems.

Data Center operators will now have more control over the PDUs that support their IT infrastructure. They can turn PDU outlets on or off and reboot outlets using Intelligent Power Manager software for increased reliability. This platform provides increased granularity for managing actions and alarms in the occurrence of a power or environmental event, and will provide more insights to the cause of an alarm so operators will be able to take precise immediate action.
GaN

Combining digital power’s capability of supporting virtually any power topology while at the same time delivering the capability of high-resolution timing control, new power elements such as Gallium Nitride (GaN) can be implemented allowing higher switching frequencies, lower switching losses, greater power density and zero reverse recovery.

In Efficient Power Conversions’ DC-DC Converter Handbook, Authors David Reusch and John Glaser comment, “Our first challenge—how will power conversion systems continue to improve in order to keep pace with the rapid improvements in computing power and the need for efficient Data Centers?”

Alex Lidow from Efficient Power Conversion told us, “As major server manufacturers such as Google reexamine the on-board power architecture, the prime candidate for improving efficiency, reducing board space, and lowering cost is to go directly from 48 V to load voltage (1.8 or 1V). This can be accomplished with silicon MOSFETs but with greater complexity and higher cost. With GaN, due to the superior switching speeds and smaller footprint, you can use simpler topologies that achieve the same or better efficiency with smaller footprints and significantly lower cost.”

For a good video by David Reusch from EPC, taken at APEC discussing these two 48V-load demo boards, see the video below. This video gives a great overview of the two demos. See Figures 22 and 23 as well.
Figure 22: From EPC: EPC9041 using eGaN IC EPC2105, Non-isolated, single-stage, high step-down ratio, 500kHz, 48V to 1.8V at 20A, Hard-switched buck converter (Image courtesy of EPC)
Texas Instruments demonstrated the TPS53632G, an analog controller that is optimized for GaN in a 48V to 1V PoL application at APEC 2016! Paired with TI’s 80-V LMG5200 GaN FET power stage, the TPS53632G controller can switch up to 1 MHz to minimize magnetic component size and reduce overall board space. The LMG5200 is designed specifically for this controller to achieve high frequency and efficiency as high as 92% with 48-V to 1-V conversion.

Summary

I await the next generation of efficiency improvements in intelligent software, maybe even on the level of Artificial Intelligence (A.I.), but nearer term, I see a move towards 480V implemented in the Data Center with the next level of efficiency improvements. I expect that GaN will assume a greater role as well in the future in these designs.
We need to begin to reduce the need for water cooling and Air Conditioning which will also greatly improve operating costs as well as the cost of ownership and to shrink the size and footprint of the Data Center.

Google has a great view into the challenging world of the data center with a birds-eye view into what a data center is and what it looks like here on this Planet Analog slideshow. You can take a virtual guided tour through Google’s data centers here as well. Google does quite an innovative series of impressive design improvements to the Data Center handling of efficiency.

It will be an exciting journey, so stay tuned to EDN for more up-to-date happenings in this effort.