

# Technical Disclosure Commons

---

Defensive Publications Series

---

June 13, 2019

## High-density voltage regulator using dual-fed bridge inductor

N/A

Follow this and additional works at: [https://www.tdcommons.org/dpubs\\_series](https://www.tdcommons.org/dpubs_series)

---

### Recommended Citation

N/A, "High-density voltage regulator using dual-fed bridge inductor", Technical Disclosure Commons, (June 13, 2019)  
[https://www.tdcommons.org/dpubs\\_series/2277](https://www.tdcommons.org/dpubs_series/2277)



This work is licensed under a [Creative Commons Attribution 4.0 License](https://creativecommons.org/licenses/by/4.0/).

This Article is brought to you for free and open access by Technical Disclosure Commons. It has been accepted for inclusion in Defensive Publications Series by an authorized administrator of Technical Disclosure Commons.

## **High-density voltage regulator using dual-fed bridge inductor**

### **ABSTRACT**

Data centers employ powerful CPUs and GPUs that consume significant amounts of current, e.g., up to a thousand amperes of current. To mitigate the large thermal losses in the power delivery network that occur at such high amperages, voltage regulators (VR) are moved closer to their loads, e.g., vertically below the loads. For a VR to fit in the tight space below the load, it must be of high density and integrate the decoupling capacitors that often occupy the space below the load. This disclosure describes a scalable, dual-fed-bridge (DFB) coupled inductor that is optimized for vertical power delivery. The DFB coupled inductor interfaces with power stage components on both its sides, resulting in high utilization of magnetic core flux density, reduced physical dimensions, and flexible layout possibilities. Decoupling capacitors are fit below the DFB inductor, resulting in further space saving and excellent transient response.

### **KEYWORDS**

- Power delivery network
- Dual-fed inductor
- Bridge inductor
- Vertical power delivery
- Decoupling capacitor
- High density VR
- Voltage regulator

### **BACKGROUND**

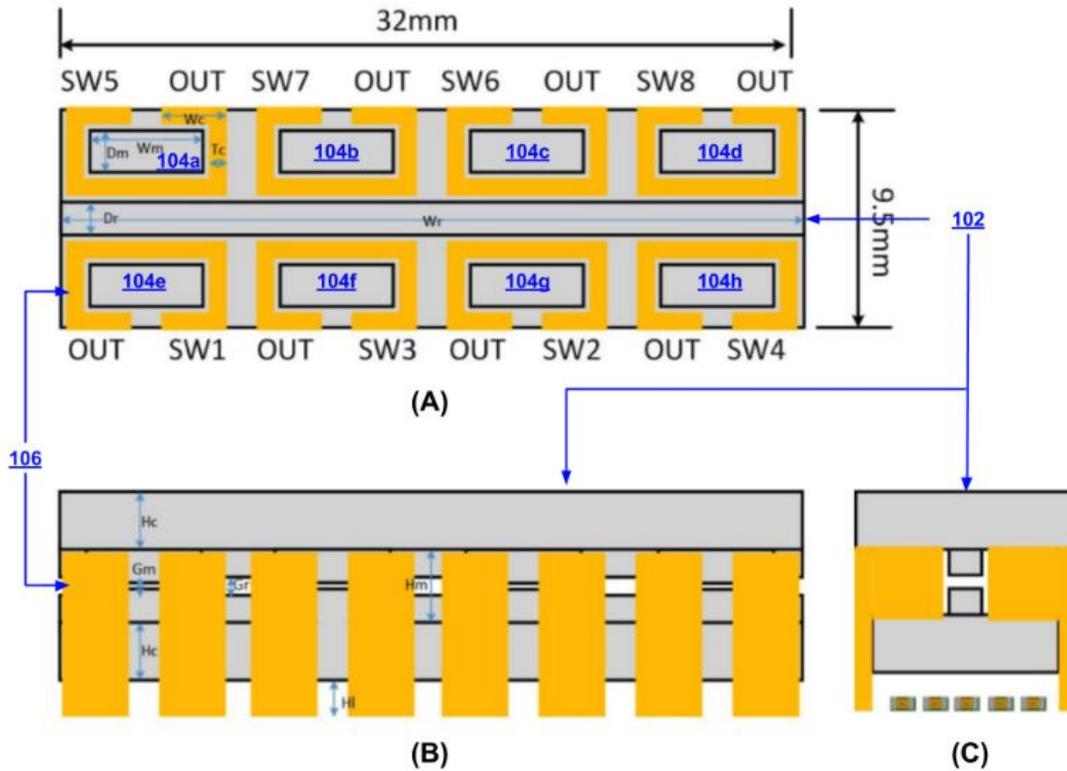
Data centers employ powerful CPUs and GPUs that consume significant amounts of current, e.g., up to a thousand amperes of current. Traditional power delivery techniques place

the point of load voltage regulator (PoL VR) on the side of the processor unit such that power is delivered laterally to the processor. However, at the high amperages of modern ASICs, the distance from the VR to its load (the processor) causes a high voltage loss (IR drop) across the power delivery network which may be unacceptable in some situations. The load suffers from low voltage and the IR drop also causes other undesirable effects, e.g., thermal loss, high temperature, lower reliability, poor dynamic voltage regulation, etc.

To mitigate large thermal losses in the power delivery network that occur at such high amperages, voltage regulators (VR) are moved closer to their loads, e.g., vertically below the loads. For example, a voltage regulator can be vertically mounted either on the bottom side of the motherboard or on the bottom of the processor package substrate. By doing so, power delivery from VR to the processor occurs on a shorter path with reduced impedance. Such vertical power delivery techniques not only reduce thermal losses, they also deliver other benefits, e.g., better transient response, lower complexity, higher reliability, greater design flexibility, better manufacturing yield, etc. For a voltage regulator to fit in the tight space vertically below its load, it must be of high density, and it must also integrate the decoupling capacitors that often occupy the space below the load.

## DESCRIPTION

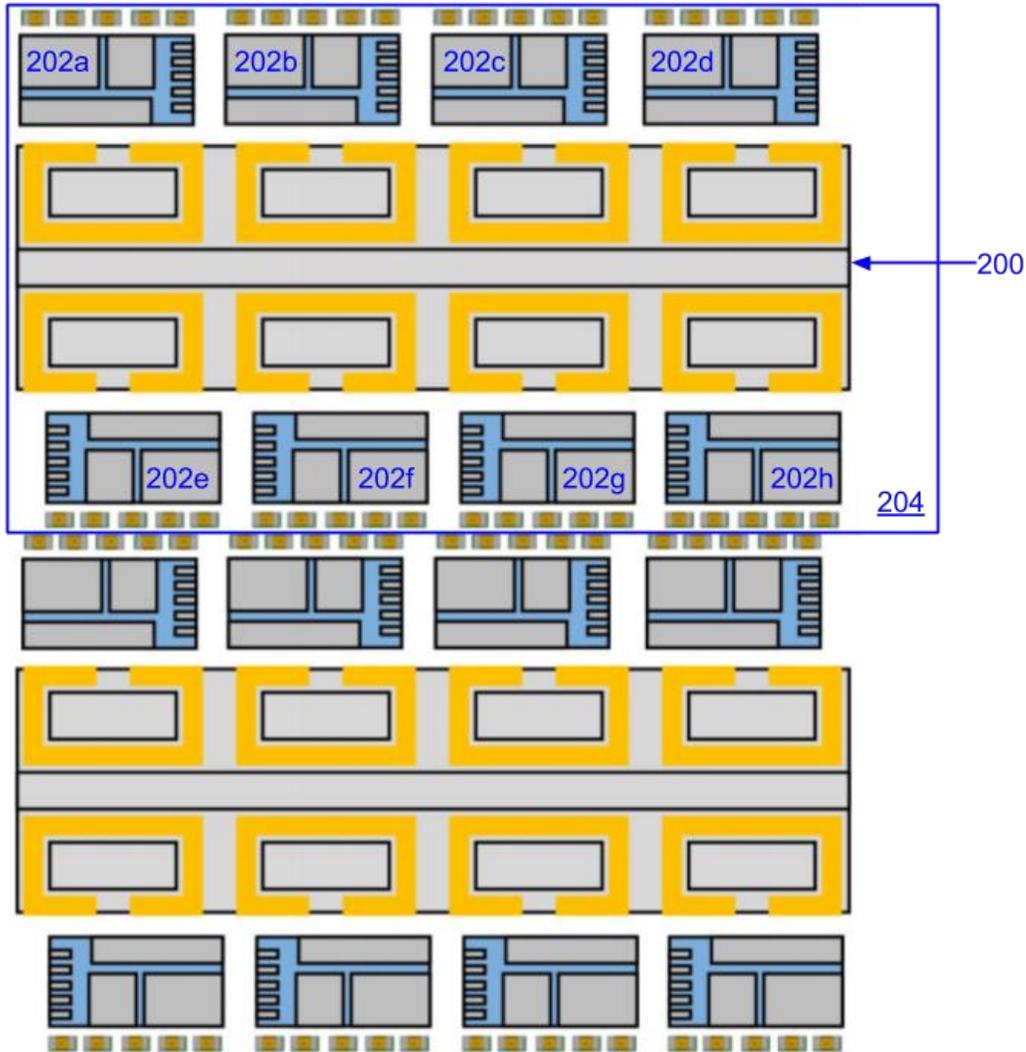
This disclosure describes a scalable, dual-fed-bridge (DFB) coupled inductor that is optimized for vertical power delivery. The DFB coupled inductor interfaces with power stage components on both its sides, resulting in high utilization of magnetic core flux density, reduced physical dimensions (reductions of about 50% of the size of conventional inductors), and flexible layout possibilities. Decoupling capacitors, e.g., of multi-layer ceramic type, are fit below the DFB inductor, resulting in further space saving and excellent transient response.



**Fig. 1: An  $N=8$  phase DFB coupled inductor: (A) Top cross-section; (B) Front view; (C) Side view**

Fig. 1 illustrates an eight-phase DFB coupled inductor with representative dimensions, in top cross-sectional (Fig. 1A), front (Fig. 1B), and side (Fig. 1C) views, per techniques of this disclosure. The inductor in this example has  $N=8$  small posts (104a-h) and one big post (102). The posts serve as inductor cores. The  $N$  small posts generate magnetizing flux for open-loop self-inductance for each of  $N$  phases, and the one big post provides a common mode leakage flux path that generates the common mode output inductance. A copper coil (106) is wound around each of the posts. There are as many phases as there are small posts, and each phase has a pulse-width modulated (PWM) waveform applied at locations SW1 through SW $N$ . The PWM waveforms are interleaved with each other, e.g., offset in phase from each other. The output voltage of the inductor is delivered on the terminals marked OUT. An eight-phase design, as

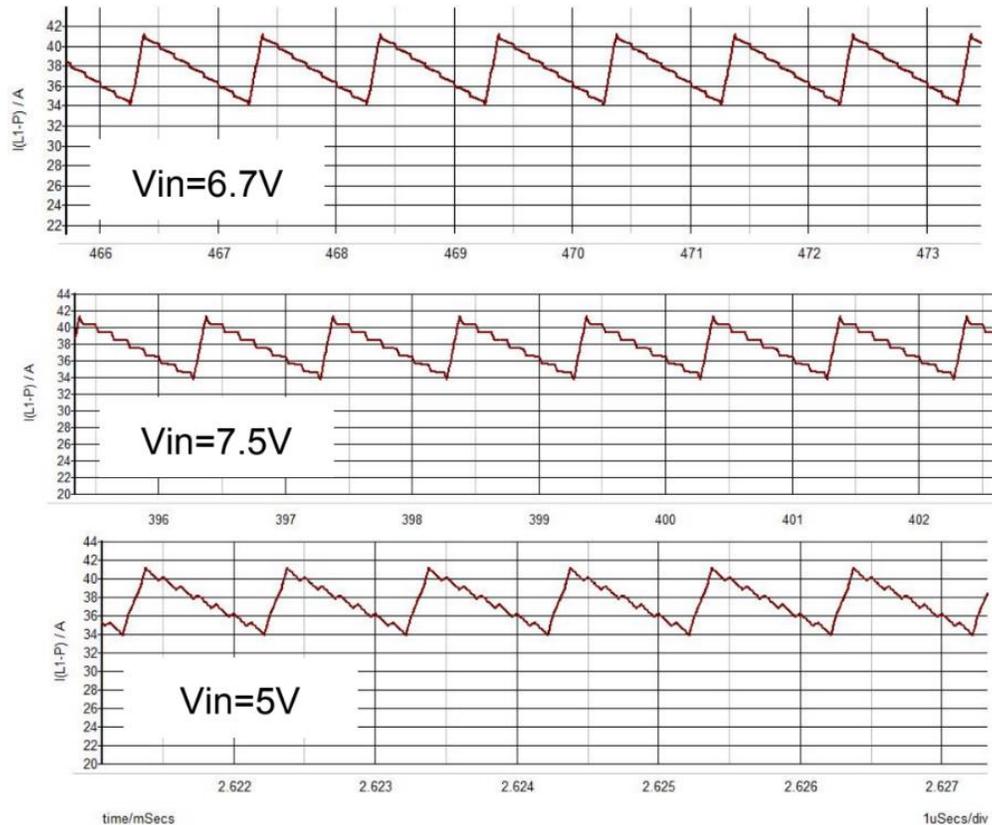
illustrated in Fig. 1, is suitable for an 8:1 voltage conversion ratio, e.g., an input voltage of 6.75 V and an output voltage of 0.8 V, under a PWM switching frequency of 1 MHz.



**Fig. 2: DFB coupled inductors in relation to their power stages**

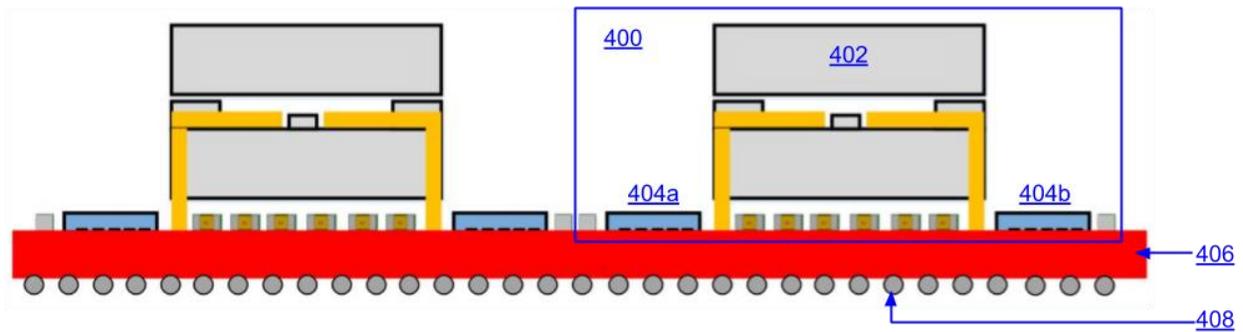
Fig. 2 illustrates a DFB coupled inductor (200) situated in relation to its power stages (202a-h), e.g., as laid out on a module PCB. The power stages comprise voltage regulator components such as MOS field-effect transistors (MOSFETs), and are placed on both sides of the inductor to feed power into it. The DFB coupled inductor together with its power stages forms a power delivery module (204). The figure illustrates two power delivery modules, e.g., a

total of sixteen phases. The power delivery modules can be mounted on a PCB interposer that itself can be mounted vertically underneath the load. Per the techniques of this disclosure, a 32mm x 9.5mm, 8-phase DFB coupled inductor design delivers as much as a maximum of 800 amperes and a thermal design current of as much as 320 amperes, while occupying a volume that is 50% of a conventional inductor.



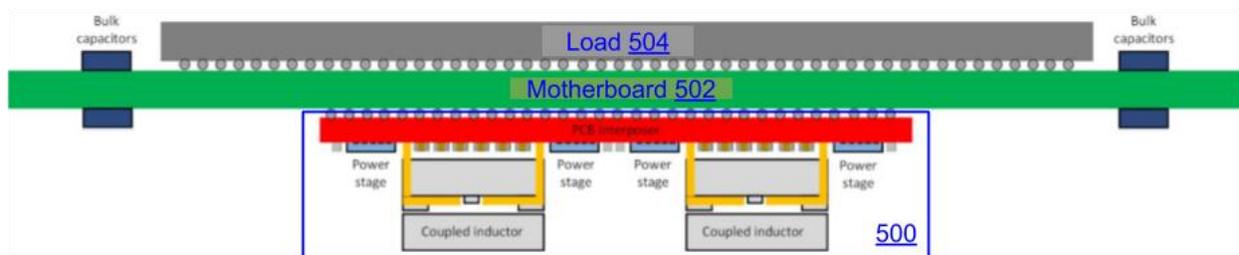
**Fig. 3: Ripple current of the output of the inductor at various input voltages**

Fig. 3 illustrates the ripple current at the output of the DFB coupled inductor at various input voltages. In this example, the output load current is 600 amperes. As is seen from Fig. 3, the ripple in the current waveforms as a fraction of their amplitude is relatively low at all input voltages.



**Fig. 4: Power delivery modules mounted on a PCB interposer**

Fig. 4 illustrates power delivery modules mounted on a PCB interposer. As explained before, a power delivery module (400) comprises a DFB coupled inductor (402) and its power stages (404a-b). The figure illustrates two power delivery modules mounted on a PCB interposer (406). The PCB interposer has surface-mount pins of type e.g., ball-grid array, land-grid array, etc. to enable mounting of the power delivery modules onto a motherboard (408).



**Fig. 5: Interposer-mounted power delivery modules in operation**

Fig. 5 illustrates interposer-mounted power delivery modules (500) in operation, e.g., supplying power to a load (504) such as an ASIC, GPU, CPU, etc. The power delivery modules are mounted on the back of the motherboard (502) that mounts the load, and for optimal thermal efficiency, situated directly vertically underneath the load.

In this manner, the techniques of this disclosure enable high-density, highly integrated voltage regulation optimized for high-current vertical power delivery. The DFB coupled inductor described herein fits easily into the small region at the bottom of a motherboard under the load,

e.g., CPU, GPU, or other processor, and enables high-efficiency vertical power delivery.

Decoupling capacitors that earlier occupied the region below the load are fit below the DFB inductor, further reducing the overall space occupied by the power delivery module and improving transient power response.

## CONCLUSION

This disclosure describes a scalable, dual-fed-bridge (DFB) coupled inductor that is optimized for vertical power delivery. The DFB coupled inductor interfaces with power stage components on both its sides, resulting in high utilization of magnetic core flux density, reduced physical dimensions, and flexible layout possibilities. Decoupling capacitors are fit below the DFB inductor, resulting in further space saving and excellent transient response.