Searching for Efficient Electrical Power System in Small Satellites

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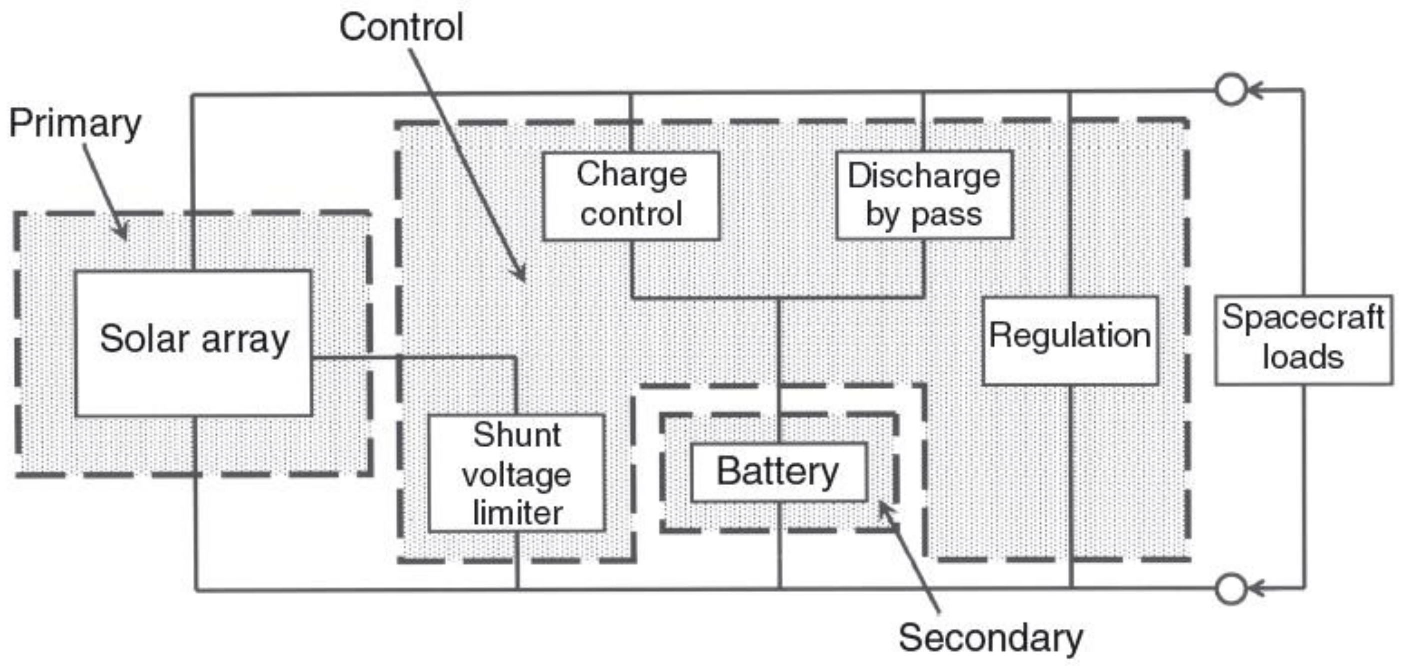
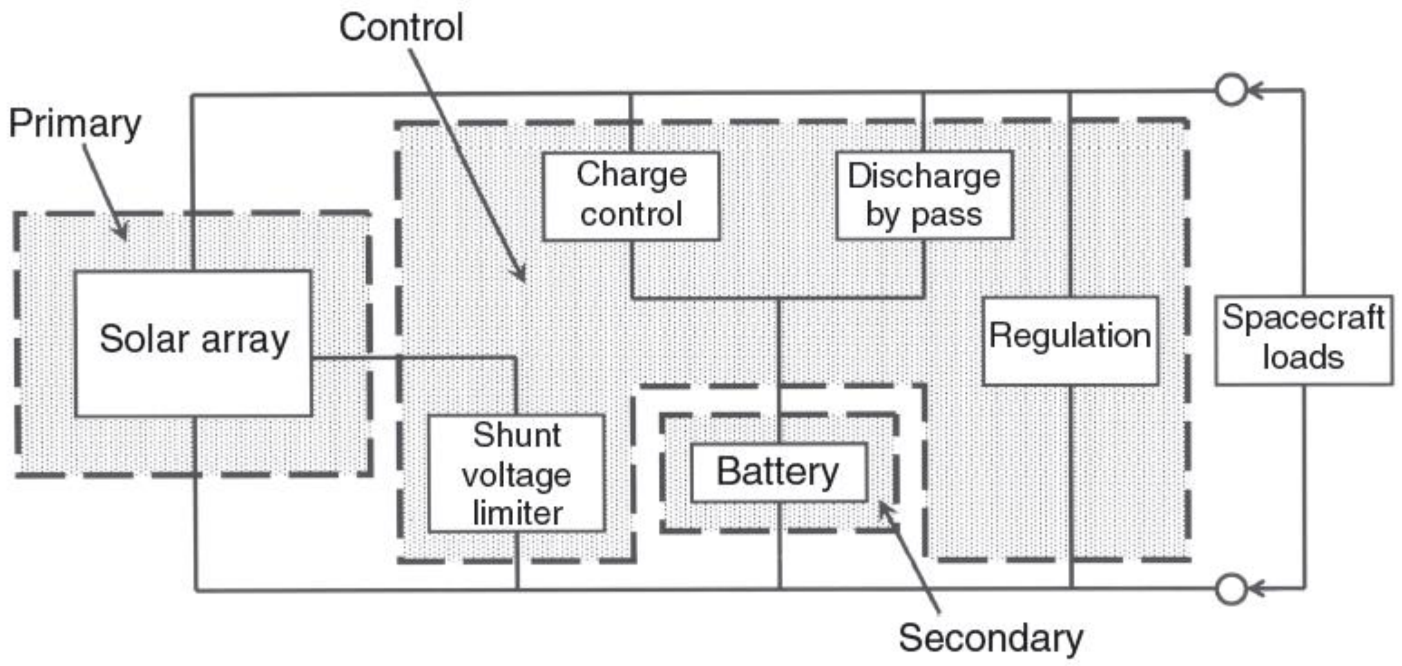
Space Seminar
2017-05-11



- Efficiency, why it is important in small satellites?
- Efficiency of solar cells and MPPT
- Losses and efficiency in power converters
  - How to improve it?



- High Efficiency
- High Reliability
- Simplicity

- What is efficiency?

"ability to do something or produce something without wasting materials, time, or energy"

"Ability of a component/system to function correctly over a specified period of time, mostly under predefined conditions"

$$\text{Efficiency} = \frac{\text{Useful Energy Output}}{\text{Energy Input}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{Useful Power Output}}{\text{Power Input}} \times 100\%$$

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- **Why efficiency is important?**

“ The EPS functionality tests revealed that the designed simple PPT controller could extract 94.2% of the generated power from Solar Arrays”

“ input power was 4.9W… average power4W of that power was converted to the bus by BCRs”

“ On average the overall system efficiency which is the ratio between input power from solar panels to output power to loads, would be 70 to 75% at most”

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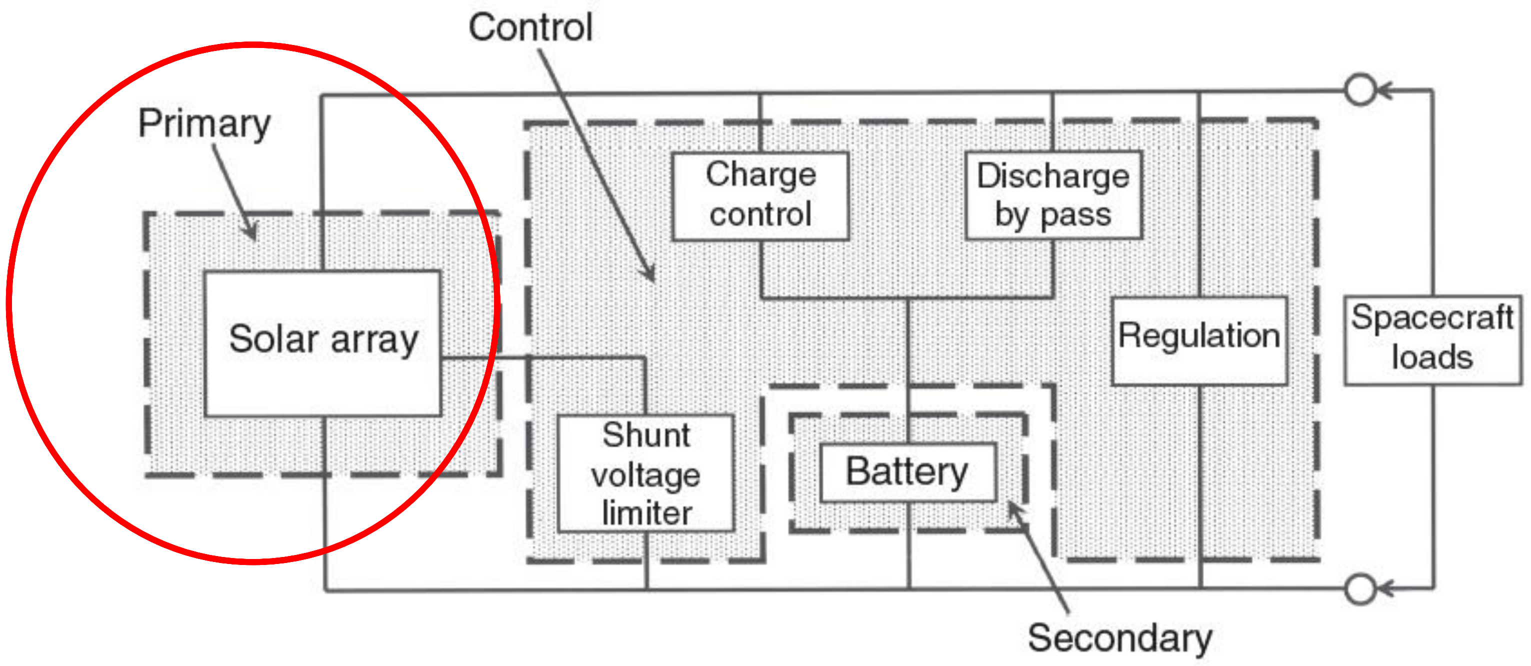
Edries, M. Y., Tanaka, A., Dashdondog, E., Almubarak, H. O., Alkali, M., Khan, A. R., … Cho, M. (2015). Design and Testing of Electrical Power Subsystem (EPS) of a Lean Satellite, HORYU-IV. In *30th International Symposium on Space Technology and Science* (pp. 7–16). Kobe, Japan.



- Efficiency in solar arrays

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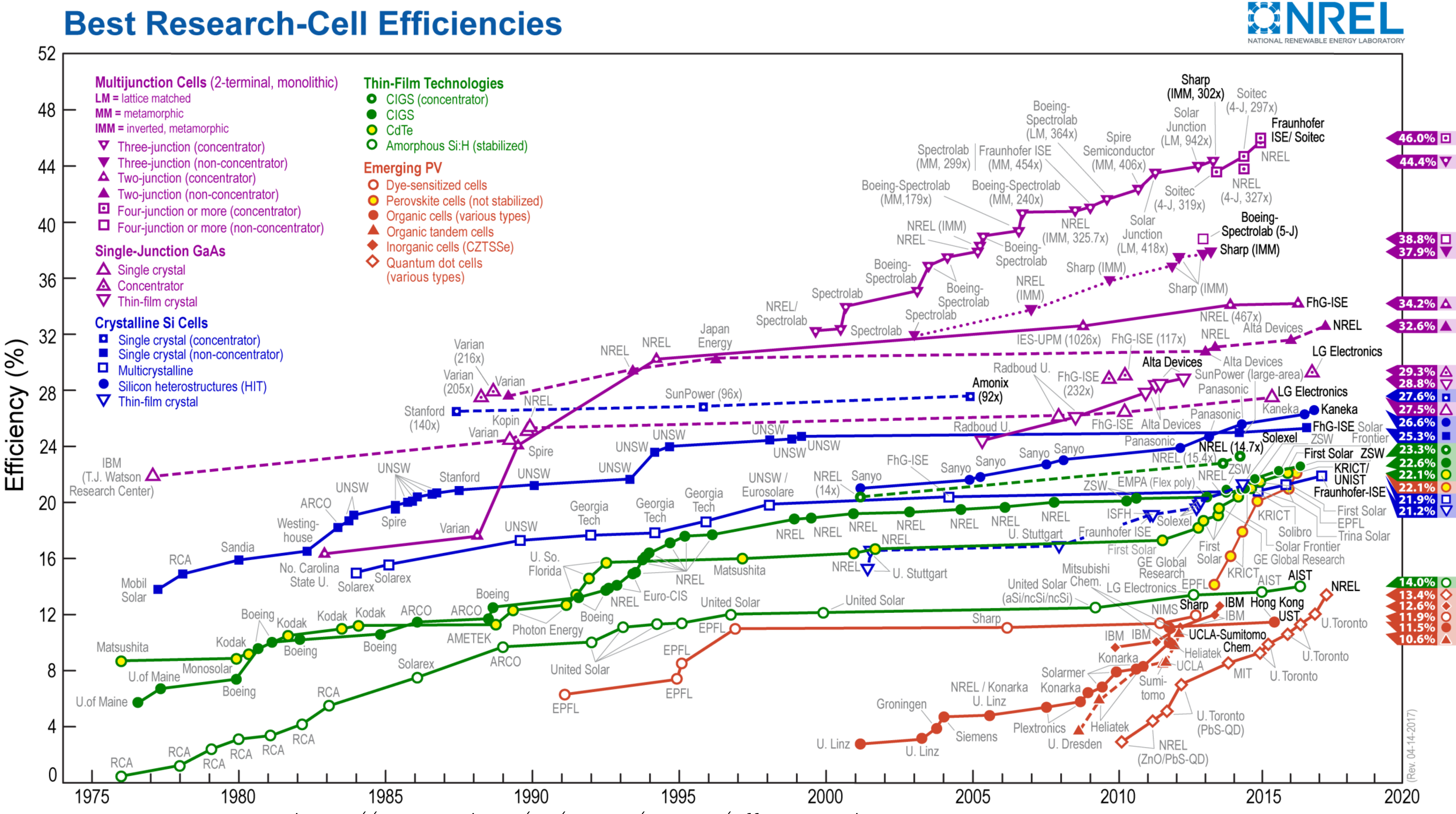

https://www.nrel.gov/pv/assets/images/efficiency-chart.png

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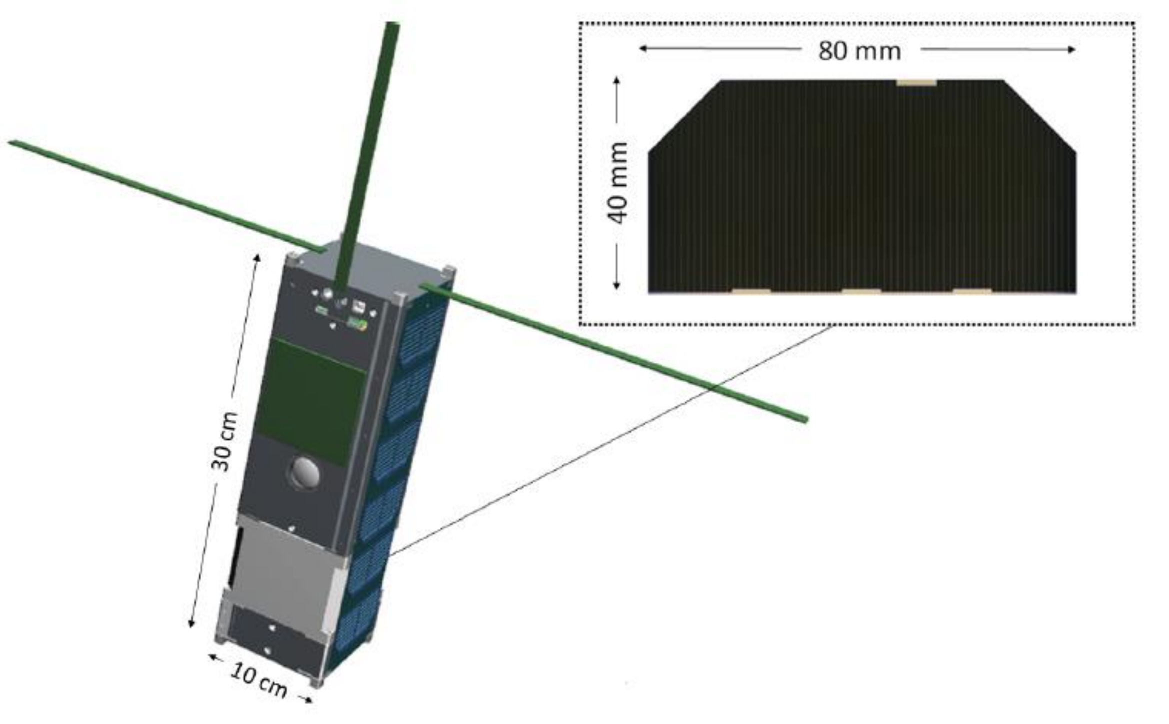
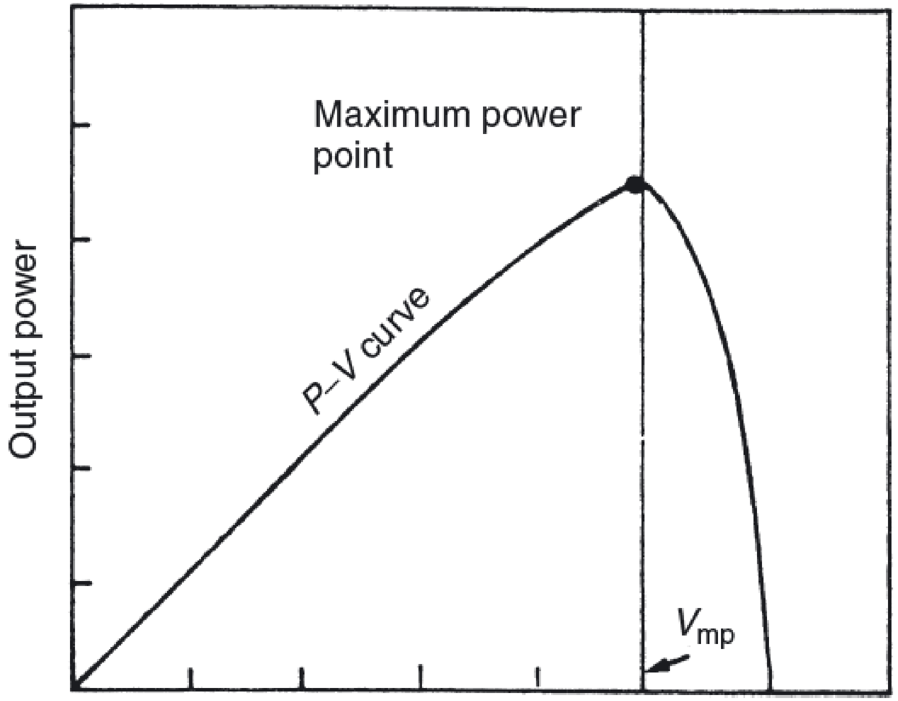


Gonzalez-Llorente, J., Rodriguez-Duarte, D., Sanchez-Sanjuan, S., & Rambal-Vecino, A. (2015). Improving the efficiency of 3U CubeSat EPS by selecting operating conditions for power converters. In *Aerospace Conference, 2015 IEEE* (pp. 1–7). http://doi.org/10.1109/AERO.2015.7119122

- Efficiency 30%
- Solar constant: 135mW/cm^2

- What is the maximum output power of this solar cell?

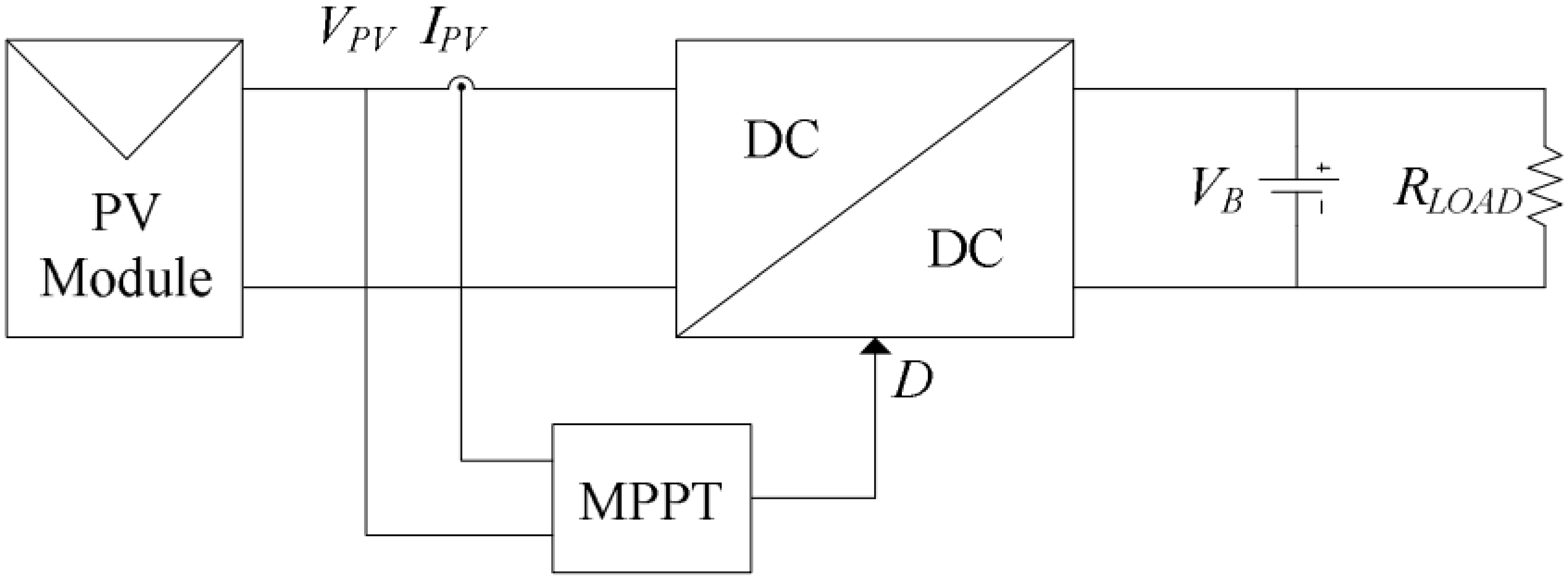


Even at 135mW/cm^2 power generation can be zero watts

(Efficiency 30%)(Solar constant 135mW/cm^2)(Area 32cm^2)=~1W

Solar Interface	Efficiency
Fractional	99.1%
Perturb and Observe	98.6%
dP/dV	98.9%
Fixed	95.7%
Temperature Compensated Fixed	99.2%
Direct Energy Transfer	86.5%

Erb, D. (2011). *Evaluating the Effectivenes of Peak Power Tracking Technologies for solar array on small spacecraft*. University of Kentucky.



MPPT requires DC-DC converters as load matching to change the operating point of the solar array

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Solar Interface	No BCR	With Expected BCR Efficiency		
	Spin 1°/s, No Radiation		Spin 20°/s, No Radiation	Spin 1°/s +Radiation
Fractional	99.1%	84.2%	67.9%	84.1%
P&O	98.6%	83.8%	52.6%	83.9%
dP/dV	98.9%	84.1%	46.7%	84.0%
Fixed	95.7%	81.3%	51.2%	57.2%
TC Fixed	99.2%	84.3%	29.1%	66.4%
DET (No BCR)	86.5%		86.5%	91.0%

Erb, D. (2011). *Evaluating the Effectivenes of Peak Power Tracking Technologies for solar array on small spacecraft*. University of Kentucky.

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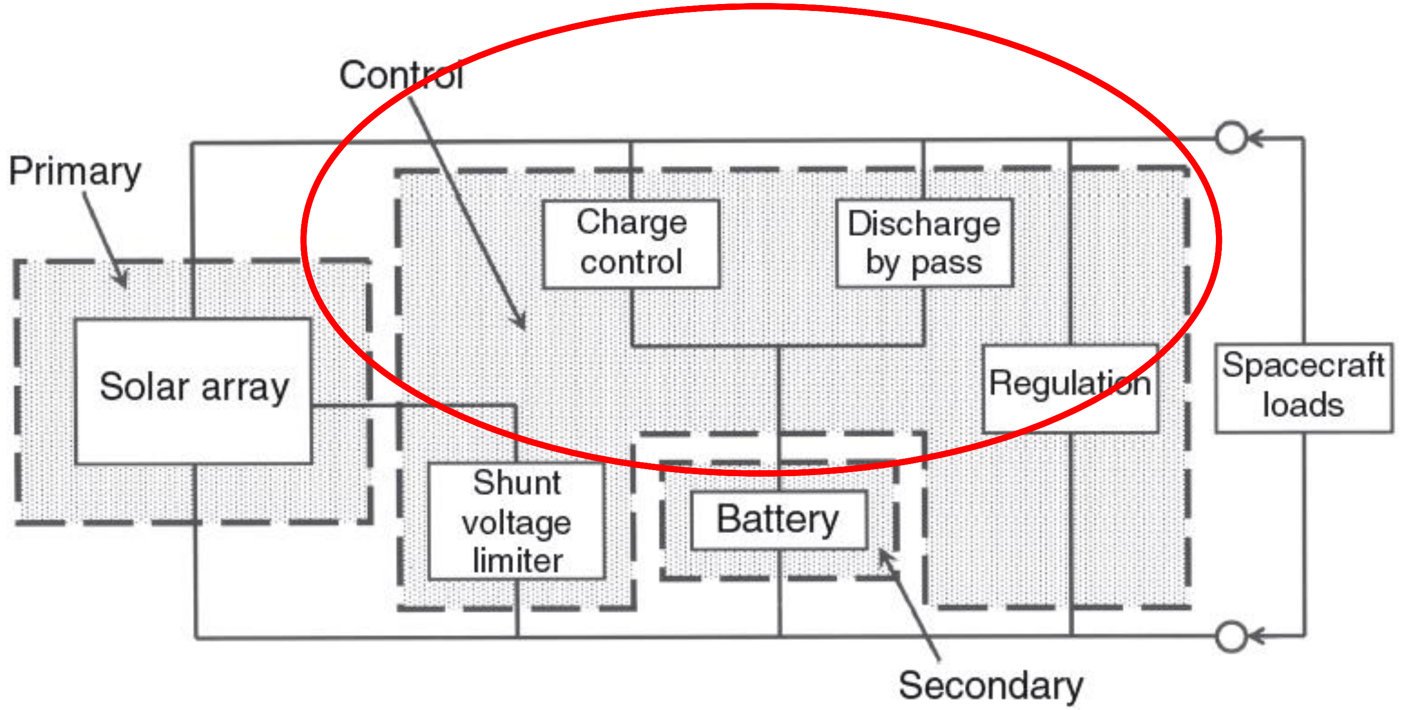
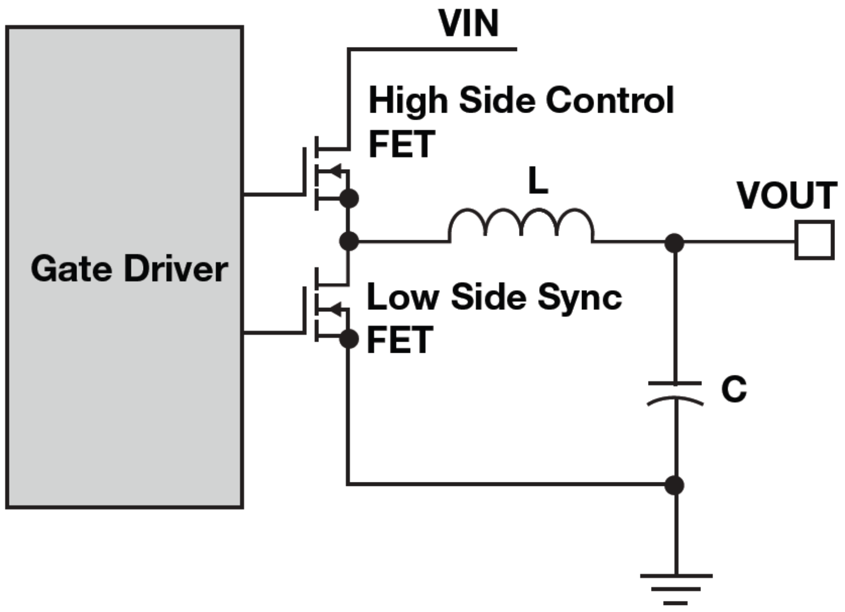
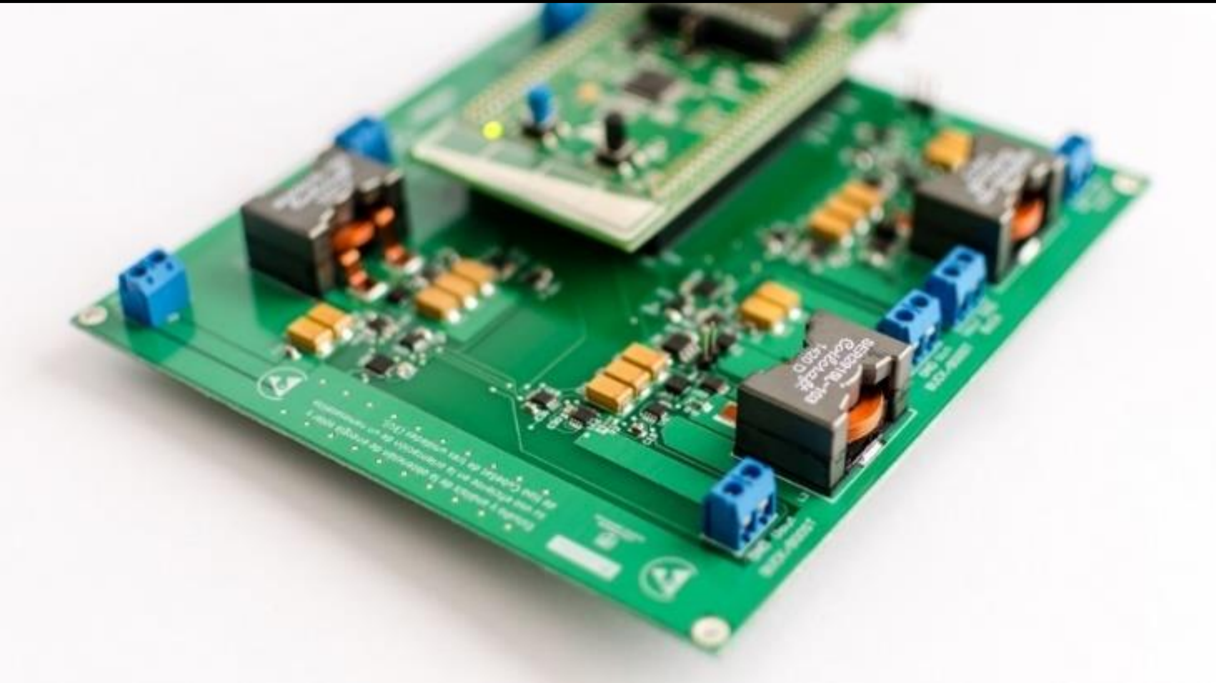


- Efficiency in power conditioning modules



“is a circuit that uses power switches and energy storage devices to transfer energy from input to output. They can step-up, step-down, and invert”

“They can be noisy and require energy management in the form of a control loop”



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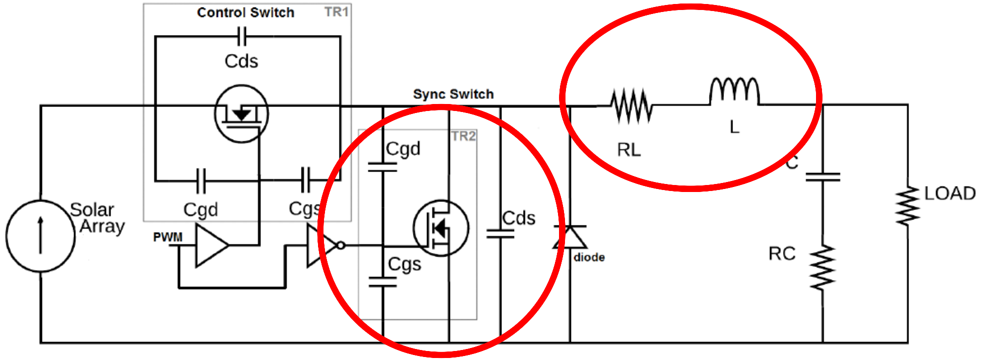

“There is parasitic elements that produce power dissipation”

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“Efficiency of power converter is reduced because power losses”

Main Losses:

$$P_{Tloss} \approx P_{cond} + P_{sw}$$

Conduction Losses:

$$P_{cond} = P_{q1} + P_{q2} + P_{wr} + P_{esr} + P_{sen}$$

Switching Losses:

$$P_{sw} = P_{turn} + P_{over} + P_{gate} + P_{core} + P_{qrr}$$

Conduction Losses:

$$P_{cond} = P_{q1} + P_{q2} + P_{wr} + P_{esr} + P_{sen}$$

Where,

$$P_{q1} = I_{o(eff)}^2 R_{DS} D$$

$$P_{q2} = I_{o(eff)}^2 R_{DS}(1 - D)$$

$$P_{wr} = I_{o(eff)}^2 R_L$$

$$P_{esr} = I_{c(eff)}^2 R_c$$

$$P_{sen} = I_{o(eff)}^2 R_{sen}$$

Switching Losses:

$$P_{sw} = P_{turn} + P_{over} + P_{gate} + P_{core} + P_{qrr}$$

Where,

$$P_{turn} = \frac{2}{3}(C_{OSS_{LS}} + C_{OSS_{HS}})V_{in}^2 f_{sw}$$

$$P_{over} = \frac{1}{2} I_p t_f f_s$$

$$P_{gate} = 2C_{iss} V_{dd}^2 f_{sw}$$

$$P_{qrr} = Q_{rr} V_{in} f_{sw}$$

$$P_{core} = k_{core} i_p^2 f_{sw}$$

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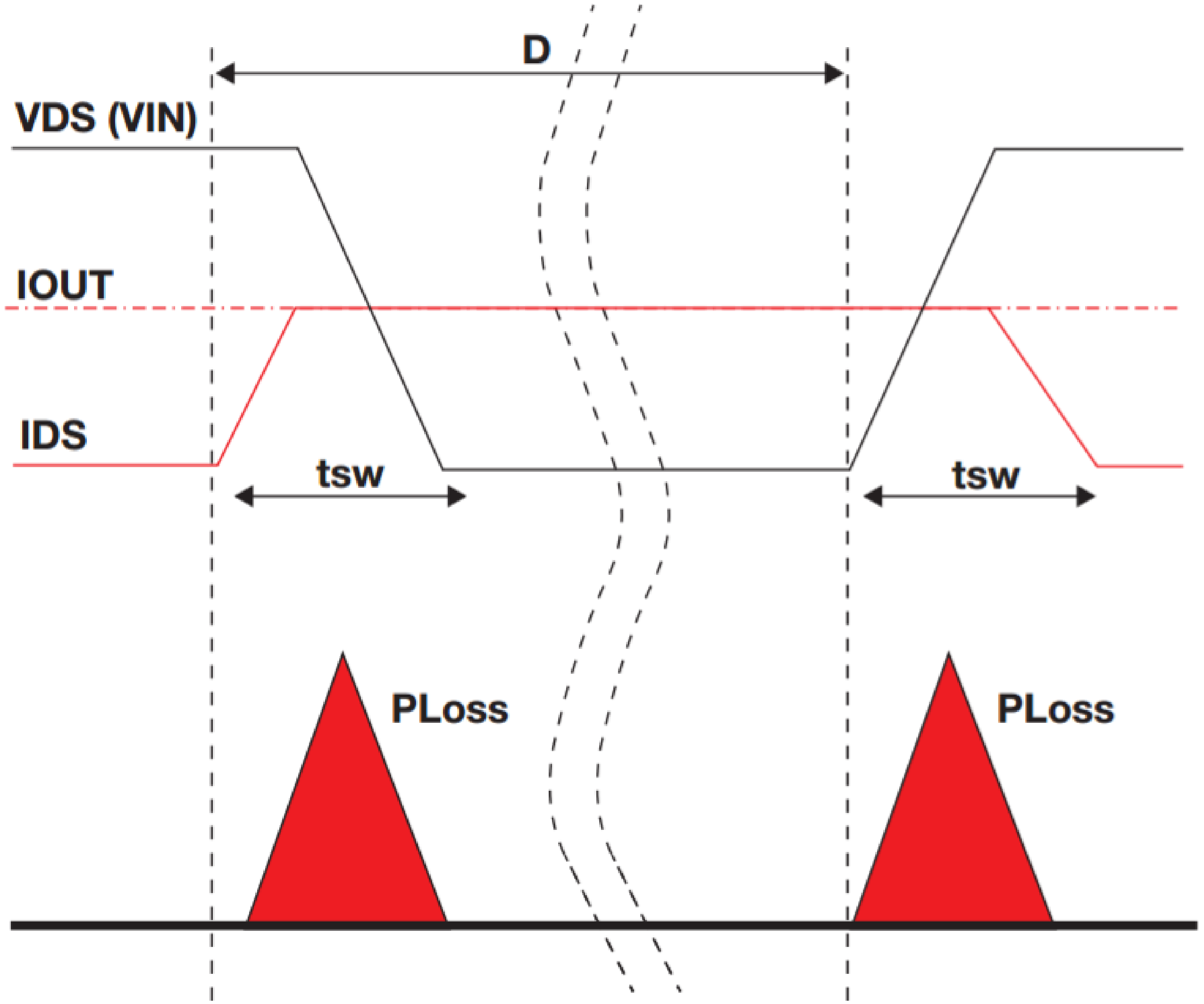
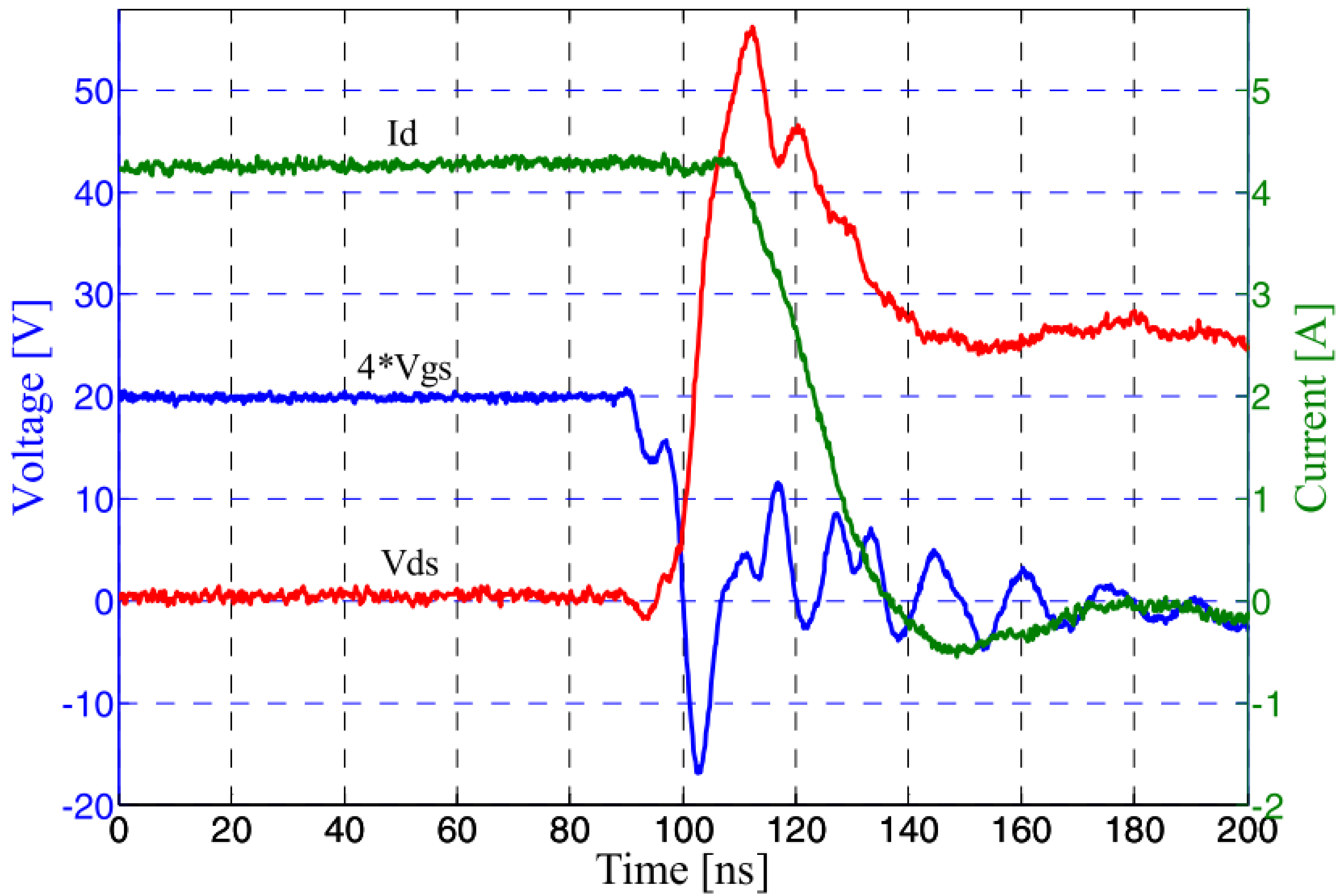
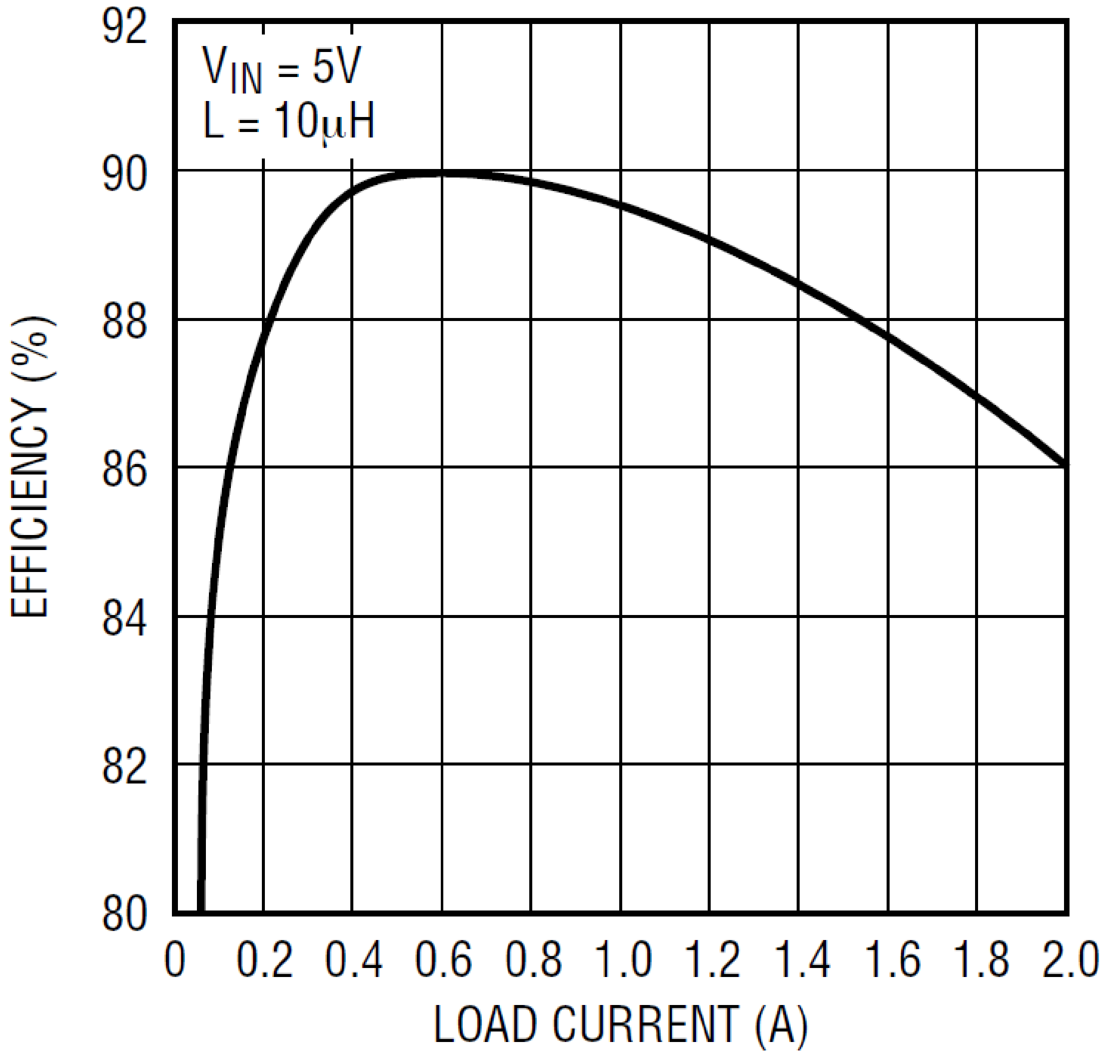


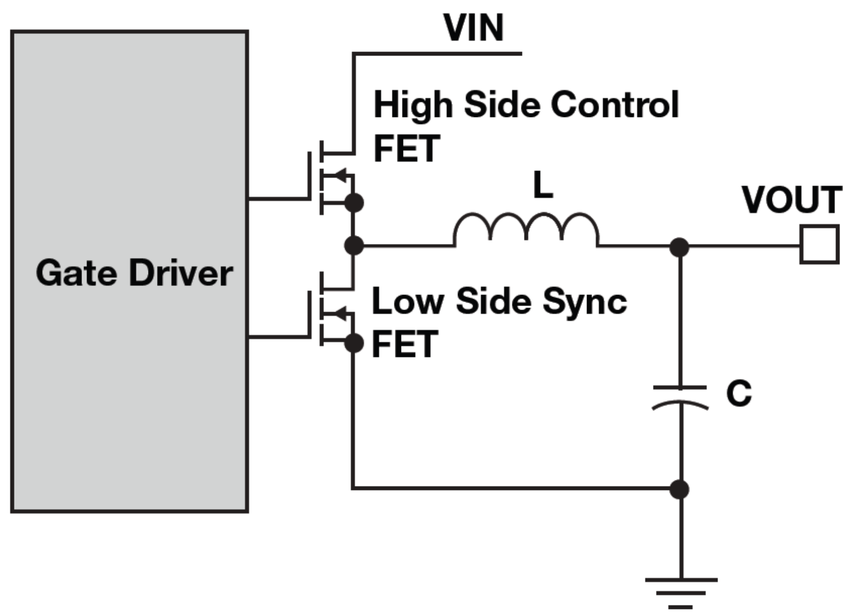
http://www.ti.com/lit/wp/slyy071/slyy071.pdf



L. Garcia-Rodriguez, E. Williams, J. C. Balda, J. Gonzalez-Llorente, E. Lindstrom, and A. Oliva, “Dual-stage microinverter design with a GaN-based interleaved flyback converter stage,” in *Energy Conversion Congress and Exposition (ECCE), 2013 IEEE*, 2013, pp. 4496–4502.

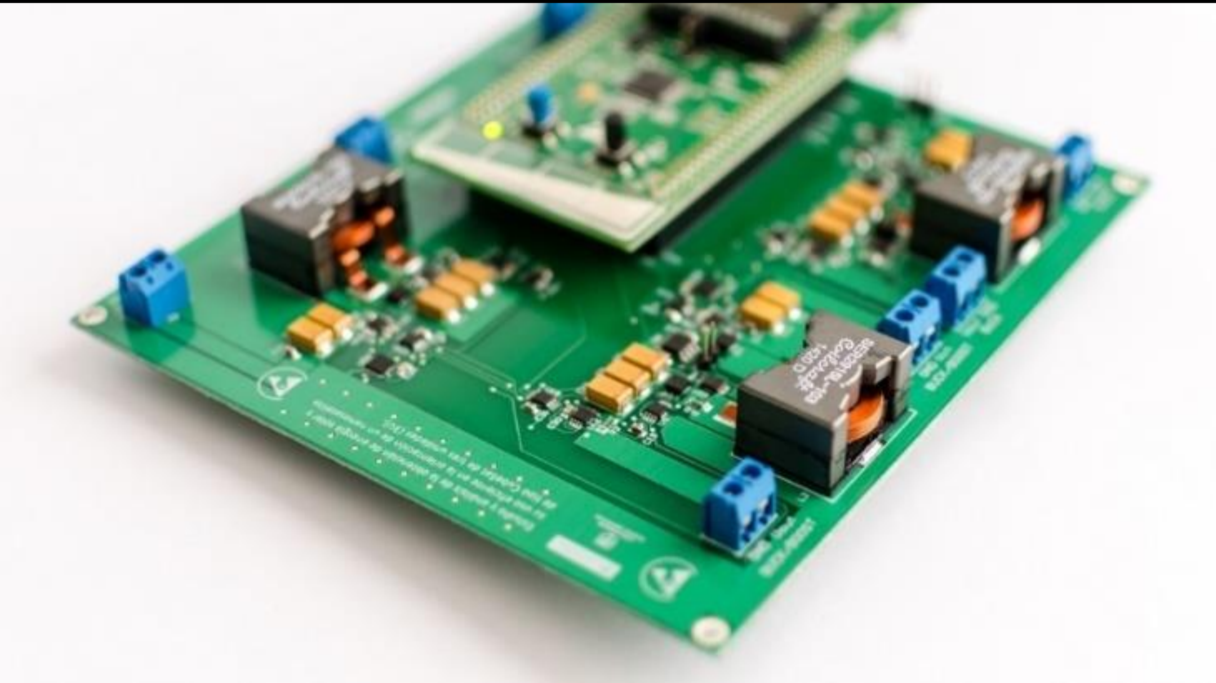


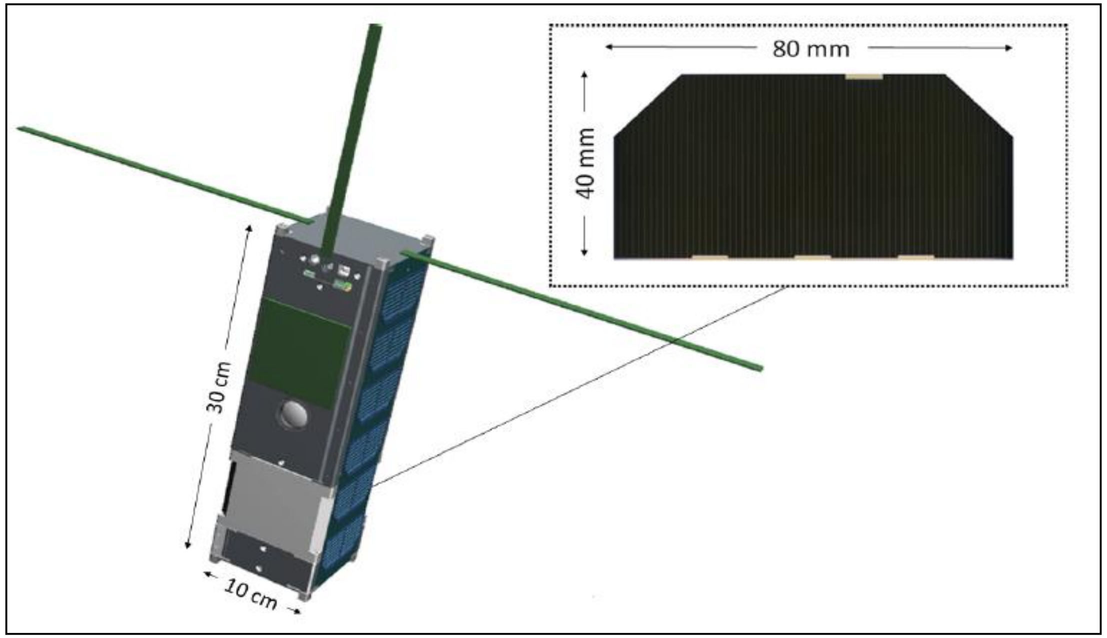
V_{IN} = 5V
L = 10μH
92
90
88
86
84
82
80
EFFICIENCY (%)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
LOAD CURRENT (A)



"improving the efficiency by selecting the operating conditions"

"Using components/technology with few parasitic elements"





"improving the efficiency by selecting the operating conditions"

Case	V_i	V_o	Solar cell in series	Solar cell in parallel	Batt in series	Batt in parallel
1	15	3.3	6	1	1	2
2	15	6.6	6	1	2	1
3	7.5	3.3	3	2	1	2
4	7.5	6.6	3	2	2	1

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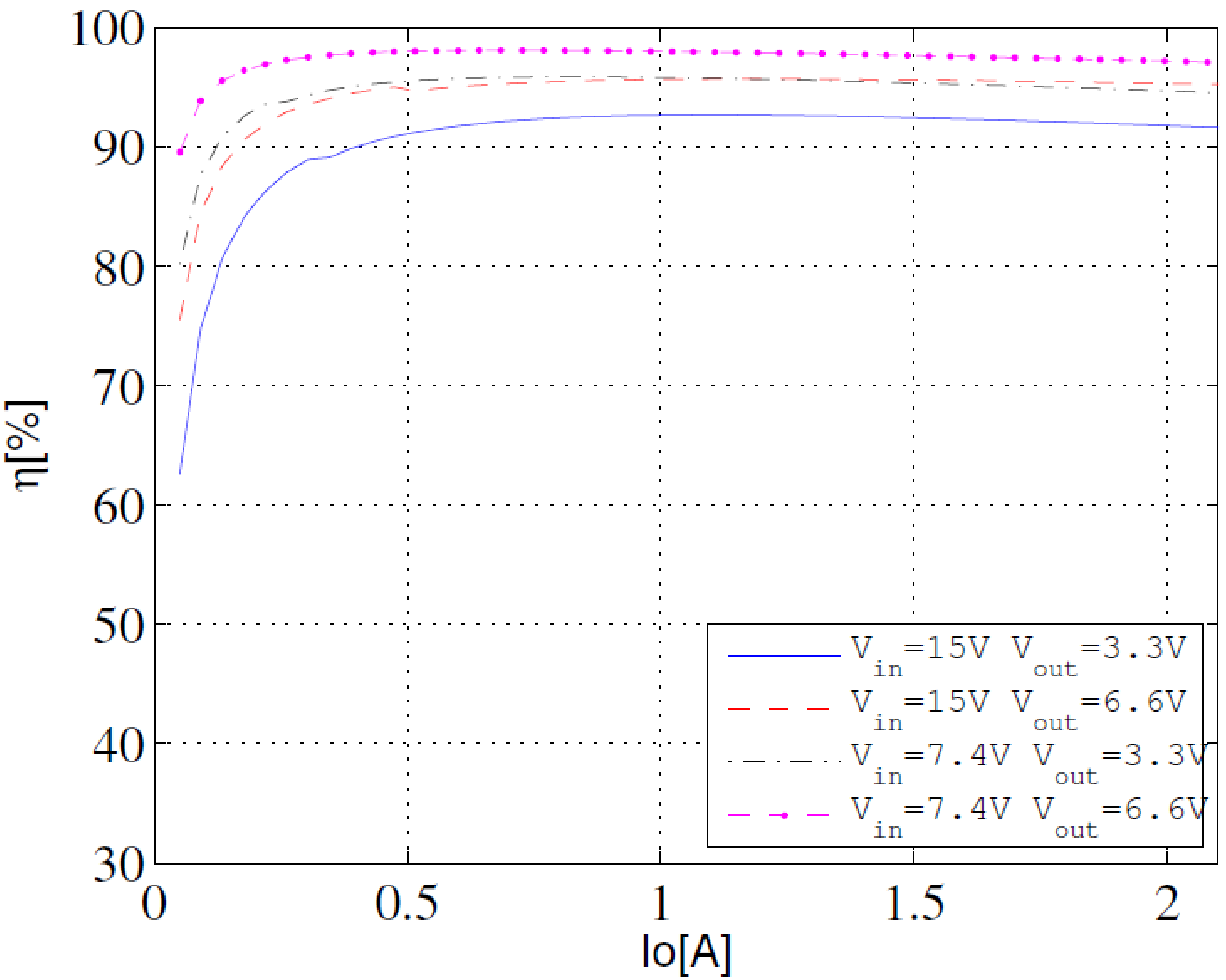

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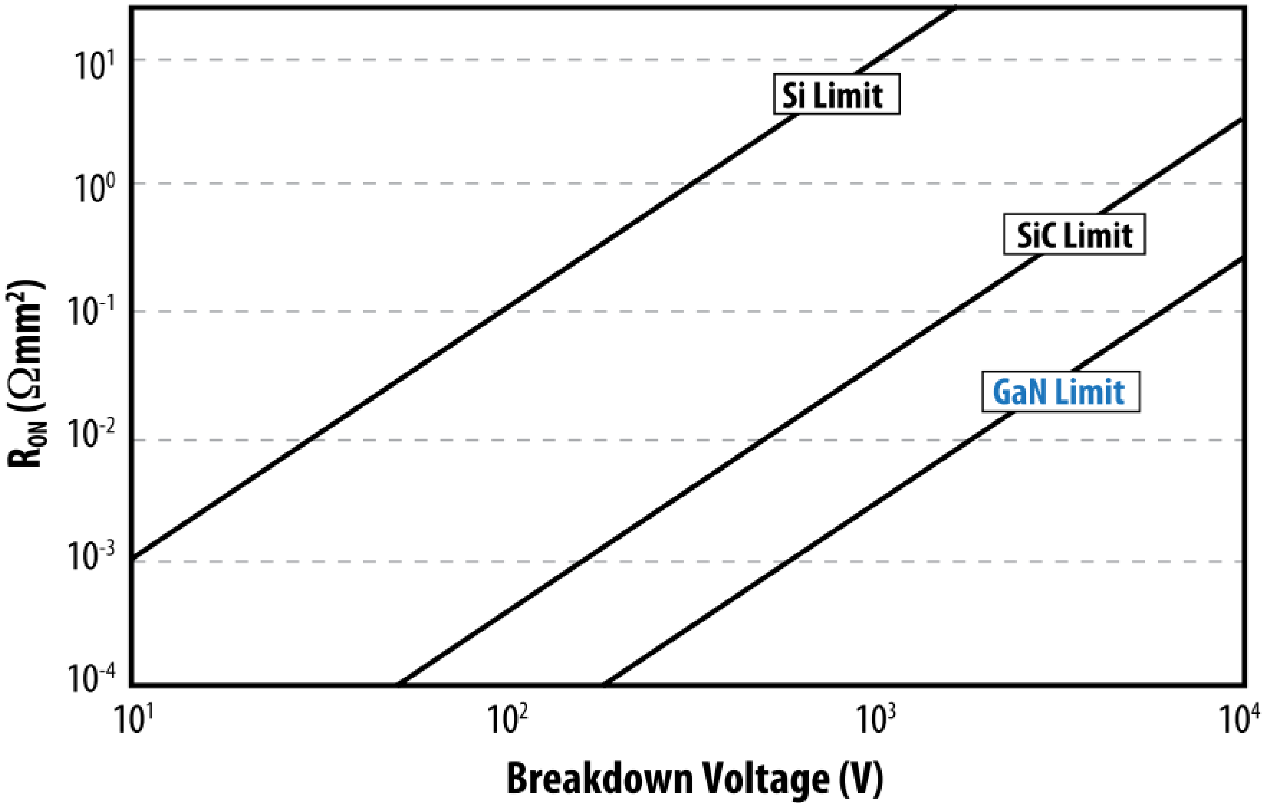
HEMT (High Electron Mobility Transistor)
gallium nitride (GaN) transistors



"Using components/technology with few parasitic elements"

http://www.power-mag.com/pdf/feature_pdf/1368025193_EPC_0313_Layout_1.pdf

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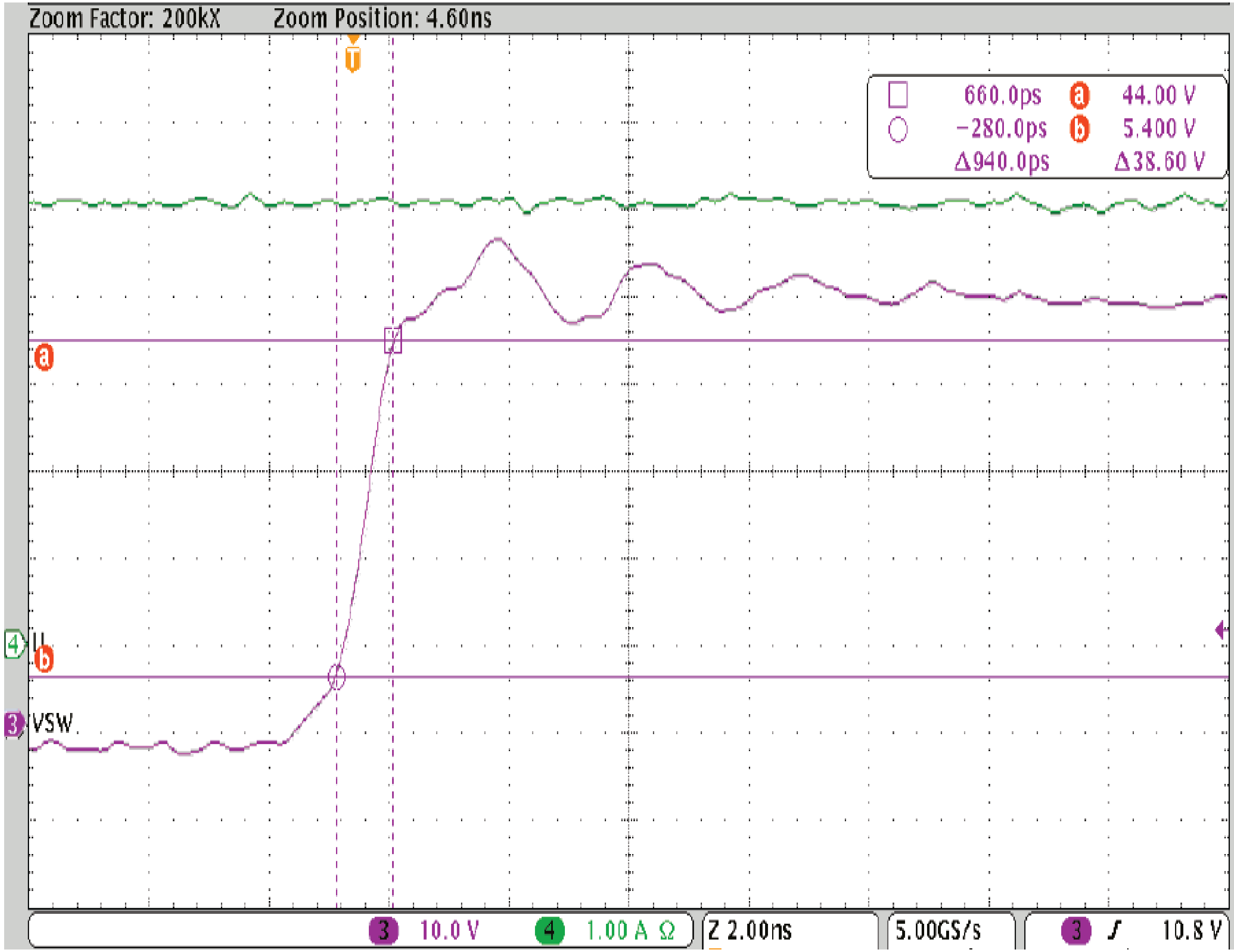

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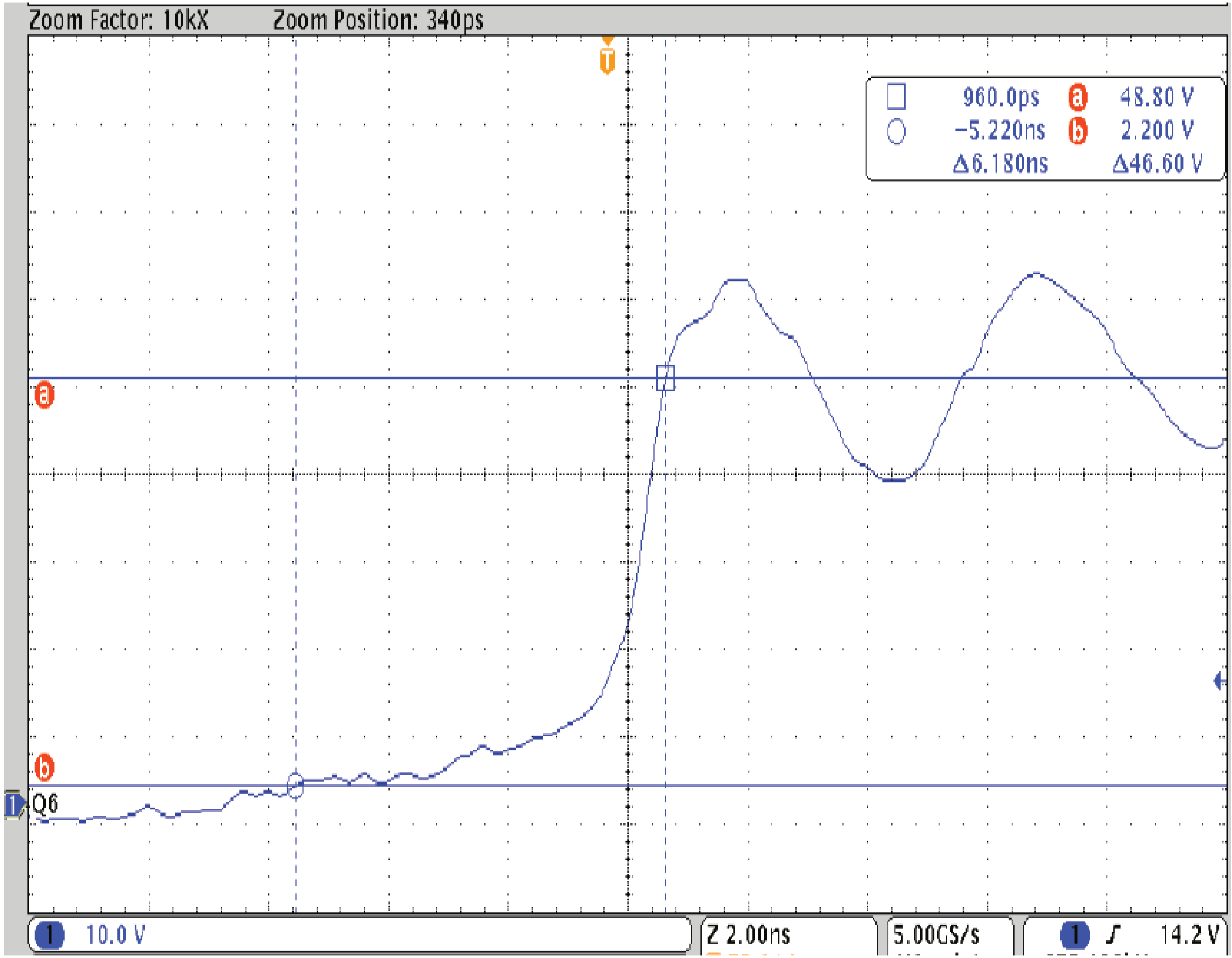

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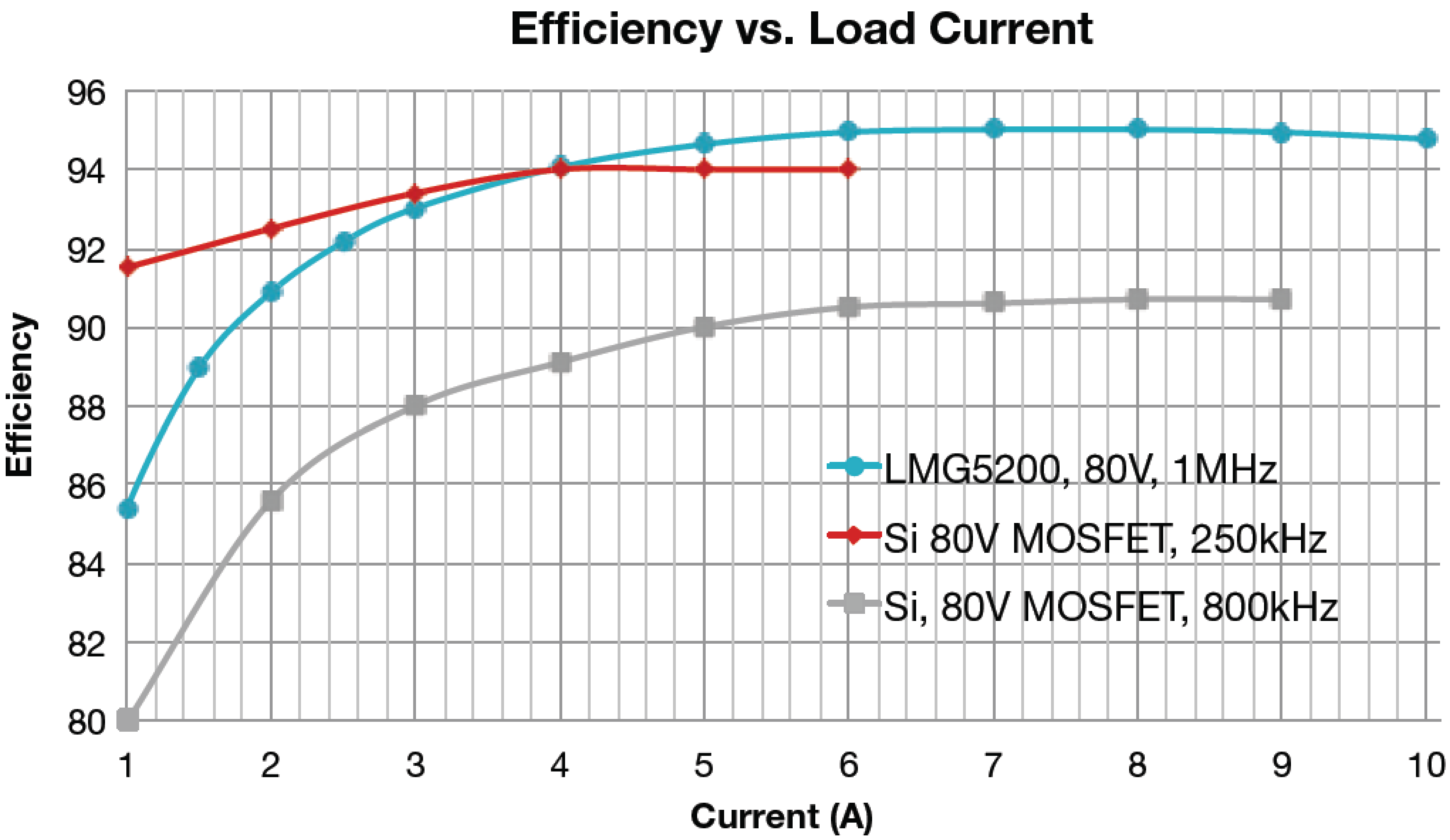

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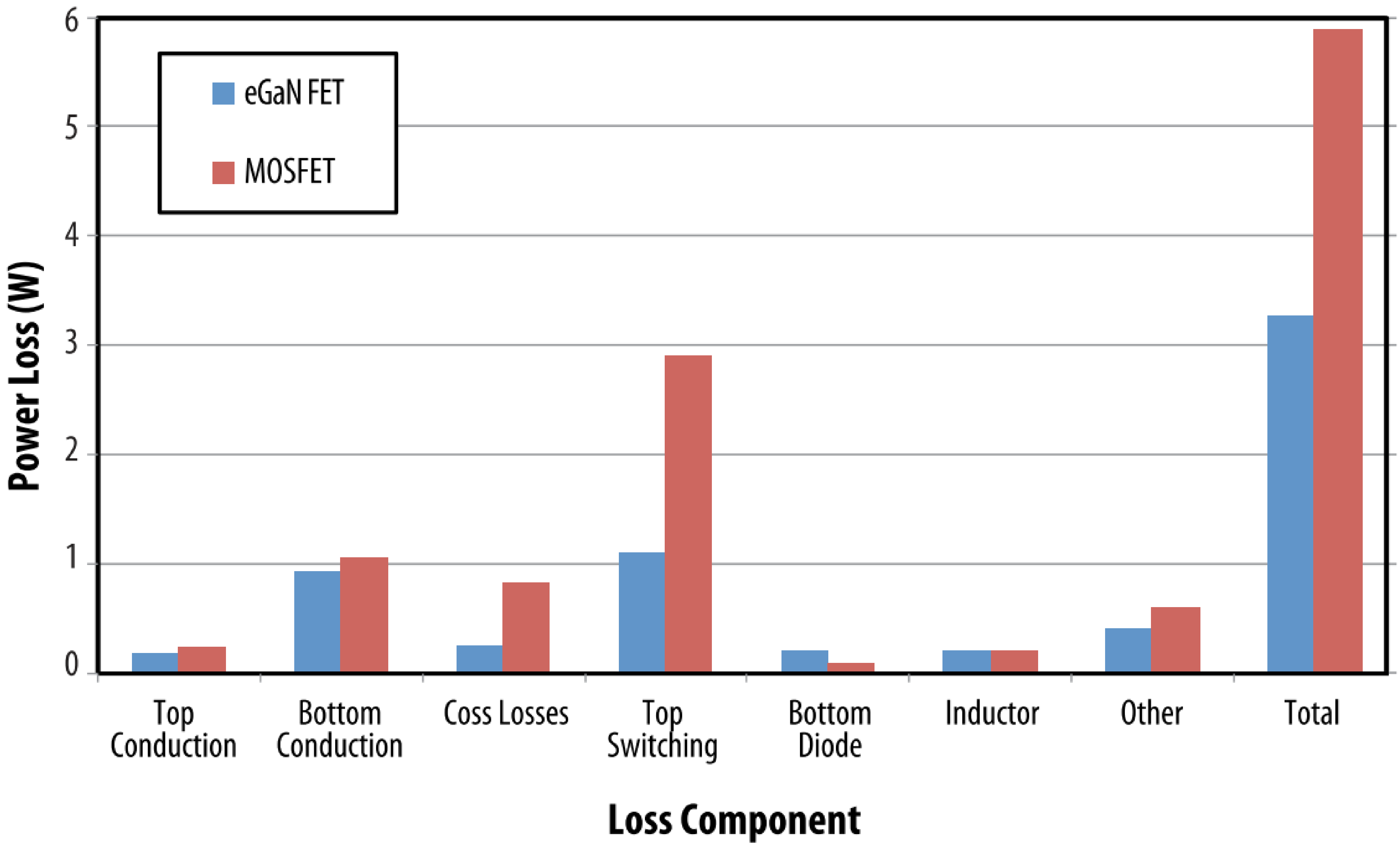

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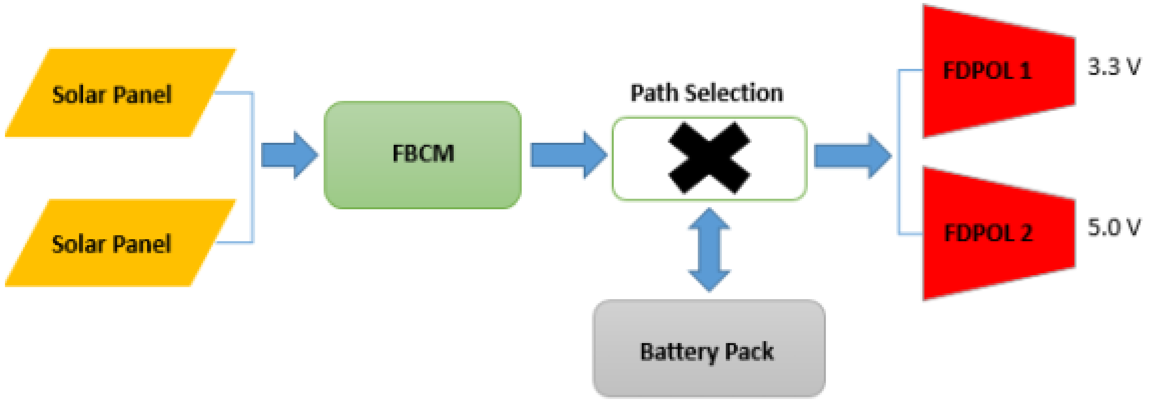
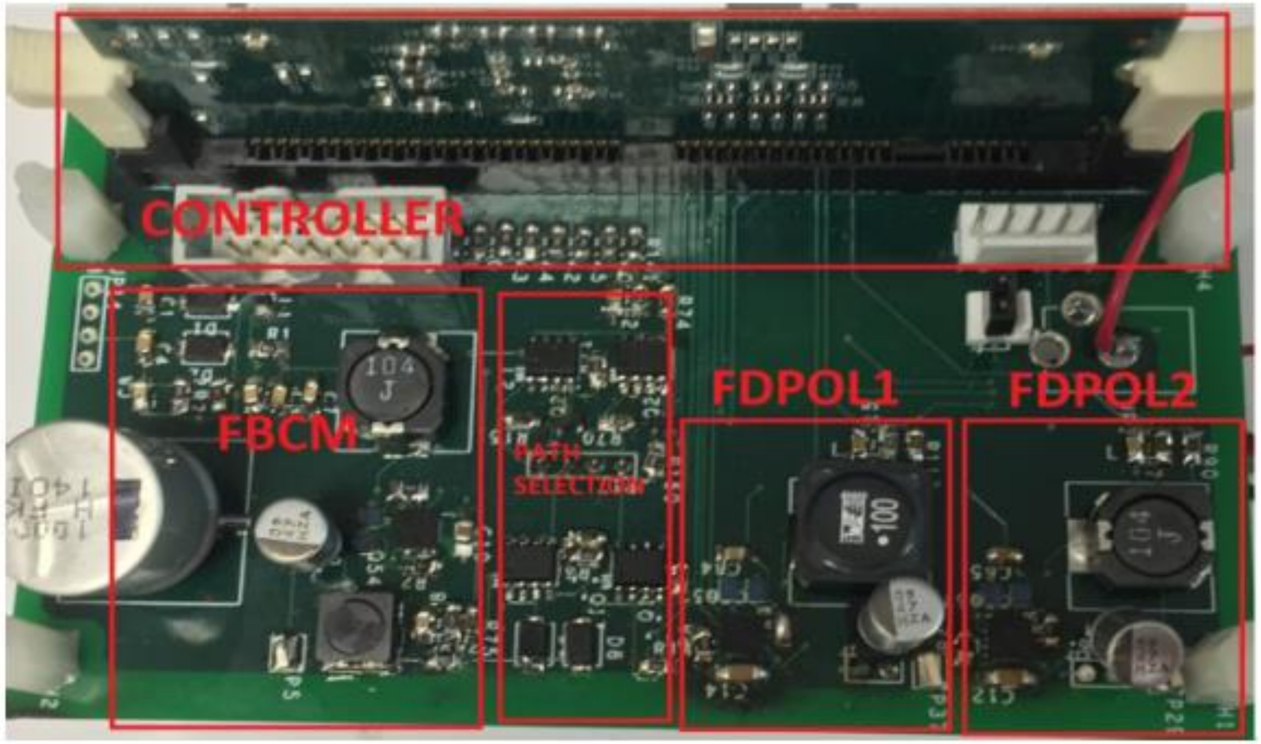


The use of GaN based devices in EPS has led to a reduction in the size and cost of magnetics



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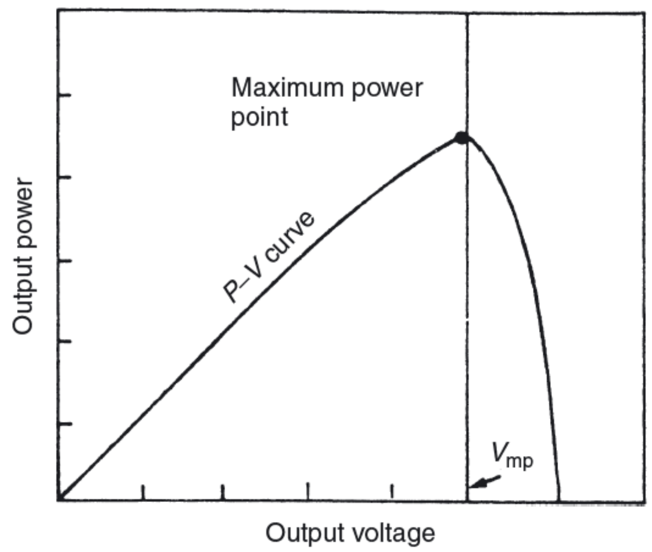
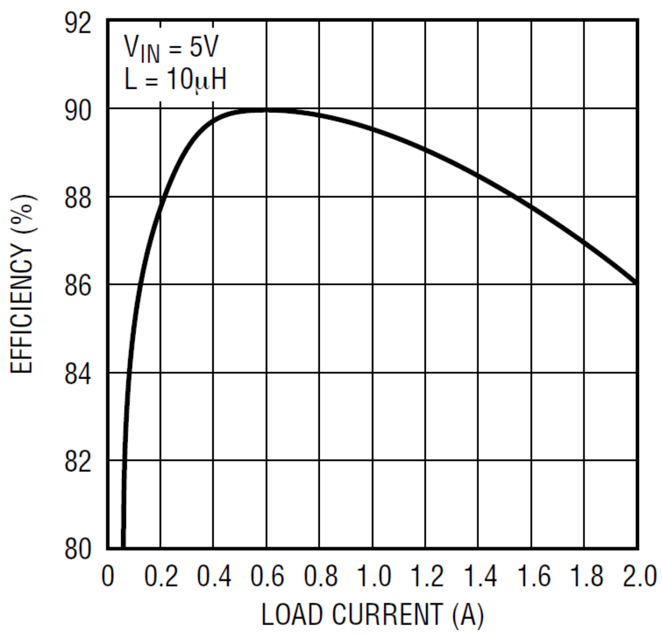
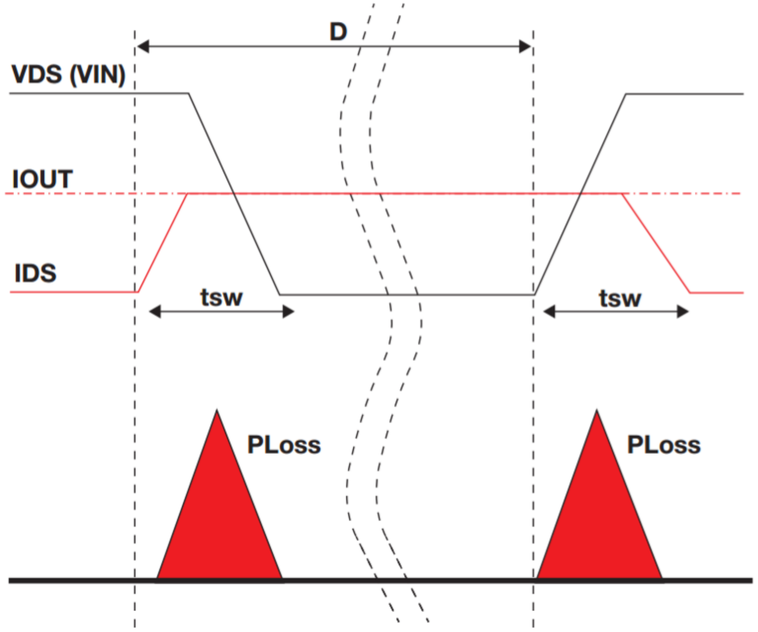
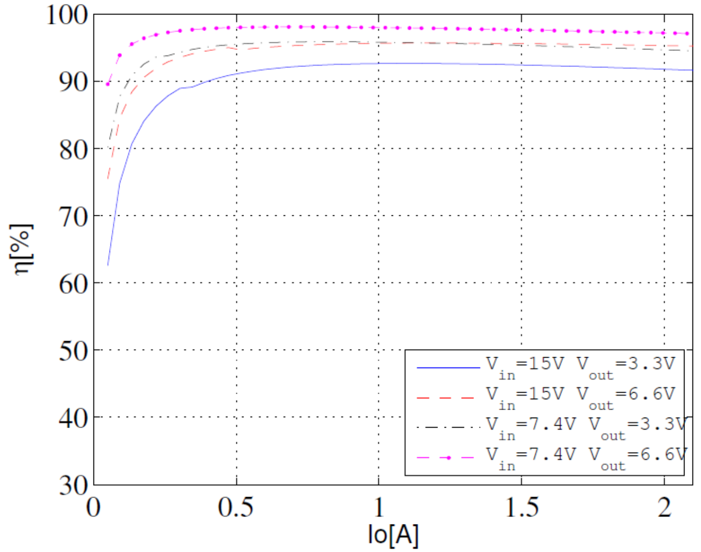
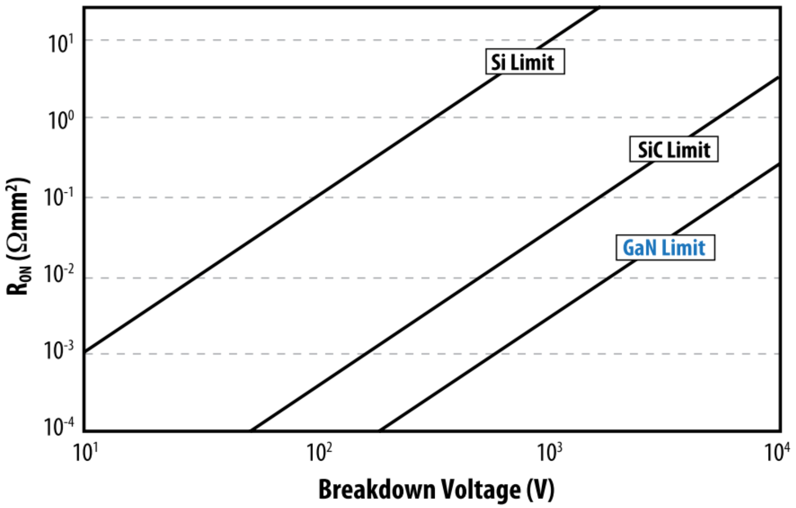
Summary

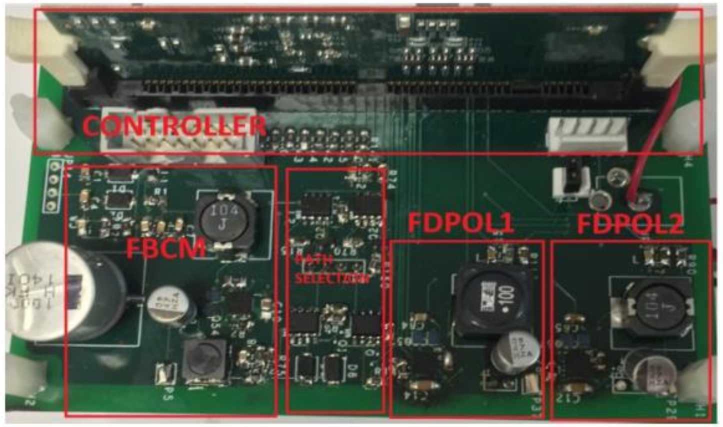












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Summary

- Efficiency of DC-DC converter depends on the operating point
- GaN transistors have lower resistance and parasitic capacitance
- DC-DC converters based on GaN use higher switching frequency reducing the size with lower losses than converters based on Si

- Efficiency of solar cells is still increasing
- MPPT techniques have high efficiency
- DET can be used in one cubesat with similar performance than MPPT

Thank you for you attention

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Email: q595903g@mail.kyutech.jp

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Question & Answers, Suggestions, Contribution!