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Isolated DC/DC Converter for RF generator of a Power Propulsion Unit: topology comparison based on GaN semiconductors

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fraza

axon' cables & connectors

AIRBUS

WITBerry CREATIVE STRATEGY

Co-funded by the European Union

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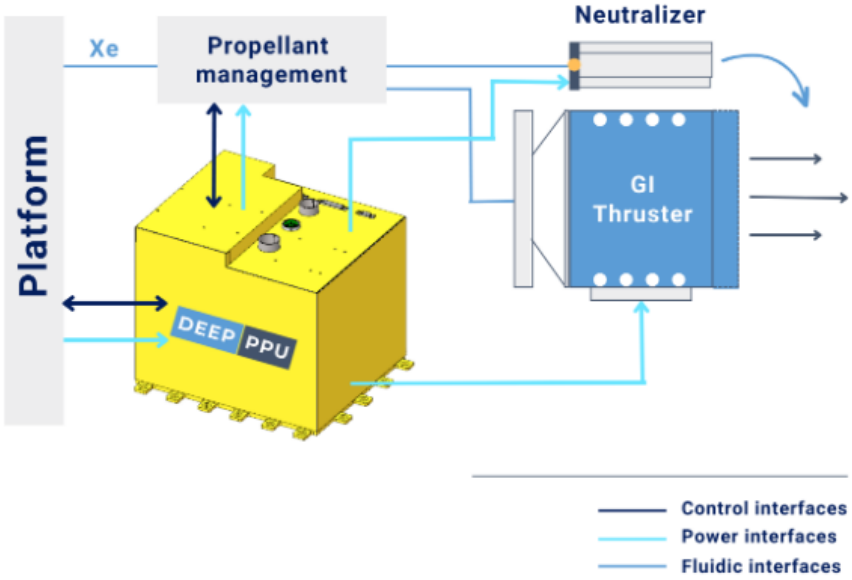
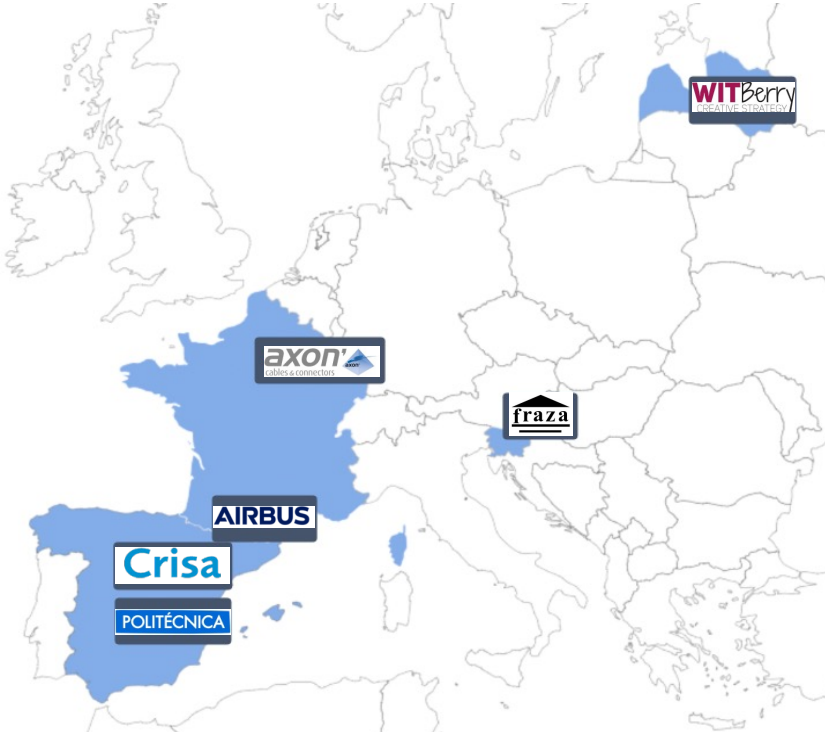
DEEP PPU project



DEEP PPU approach Source: DEEP PPU



DEEP PPU approach Source: DEEP PPU

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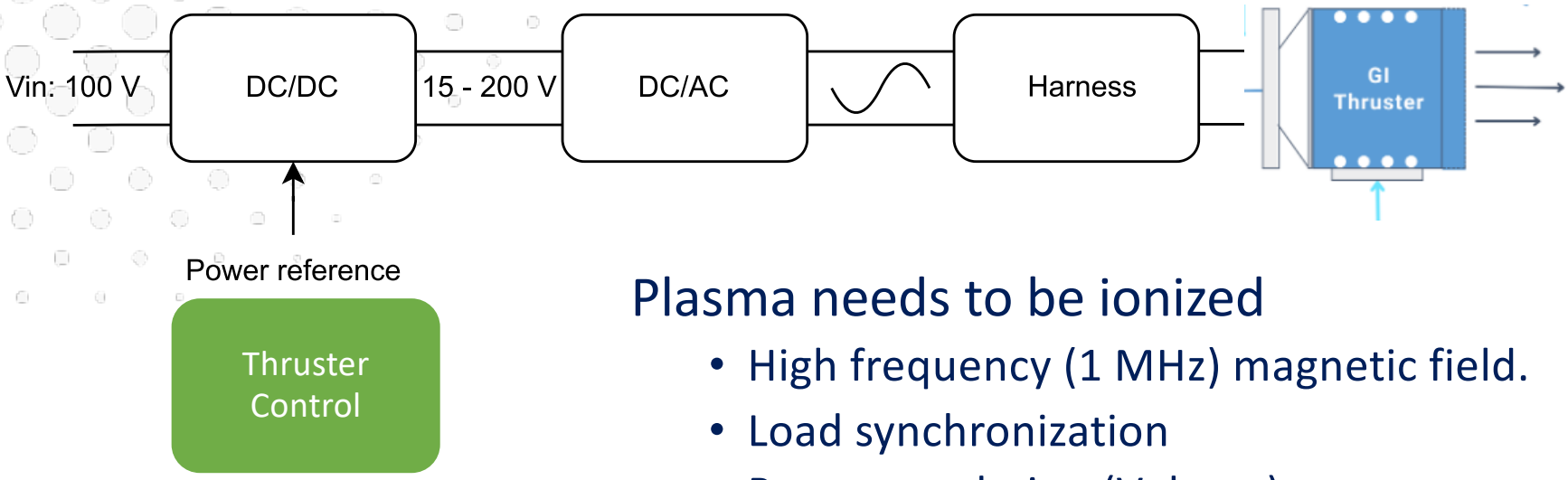
Radio Frequency Generator (RFG) Architecture



Plasma needs to be ionized

- High frequency (1 MHz) magnetic field.
- Load synchronization
- Power regulation (Voltage)
- Demanding regulation capability (15V – 200V)

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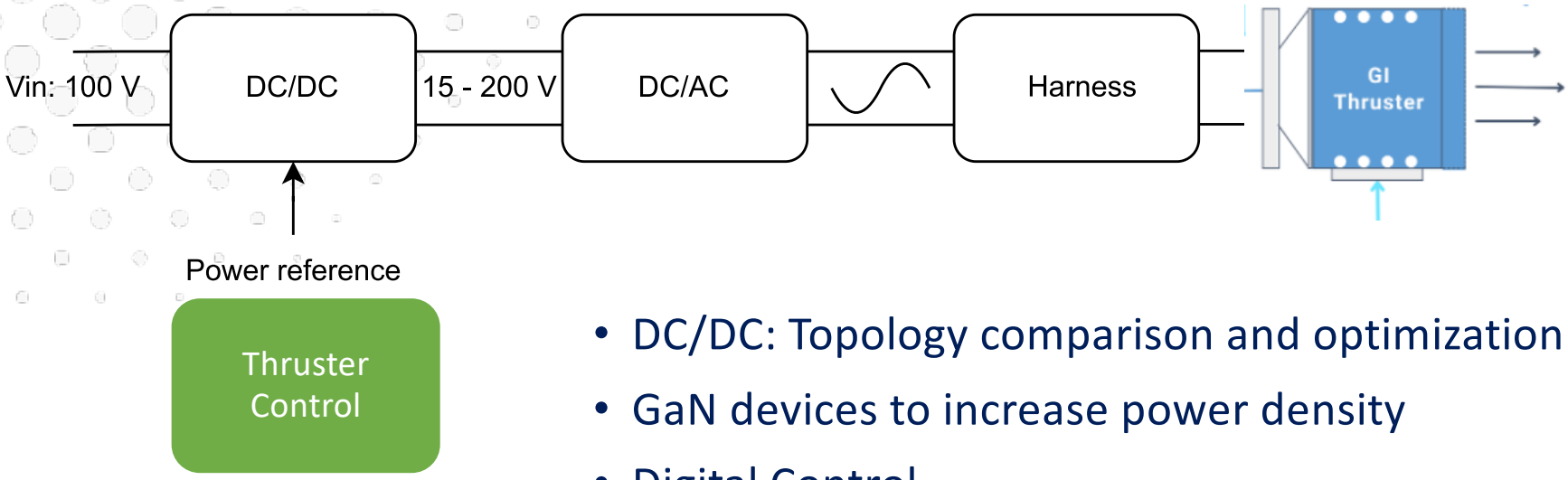
Challenges and enabling technologies



- DC/DC: Topology comparison and optimization
- GaN devices to increase power density
- Digital Control

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DC/DC
Topology comparison

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Requirements:

Wide output voltage range needed → $15 \sim 200V$
1kW of output power
Isolation is required

Analyzed Topologies
- Dual Active Bridge
- Phase Shift Full Bridge
- Flyback
- Buck + LLC

All topologies compared at 500kHz

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Topology Comparison

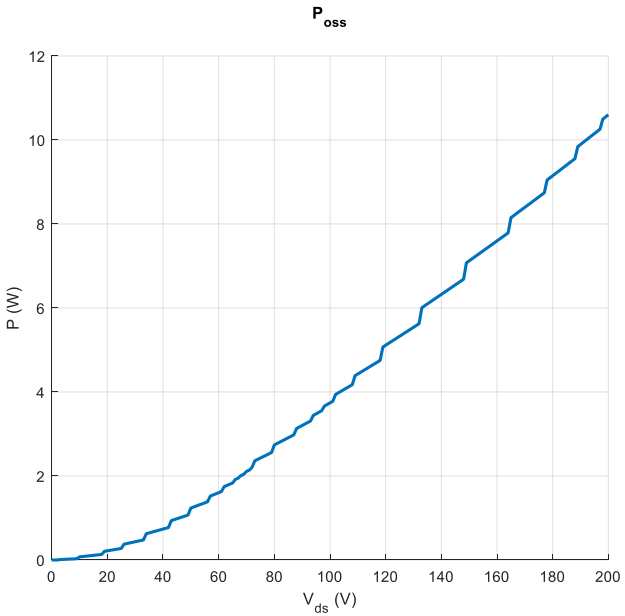
Volume
- Magnetics
- Capacitors

Losses

MOSFET Selection to Minimize Losses in Low-Output-Voltage DC-DC Converters.

Jon Gladish, Fairchild Semiconductor

High Coss charge
ZVS becomes a must



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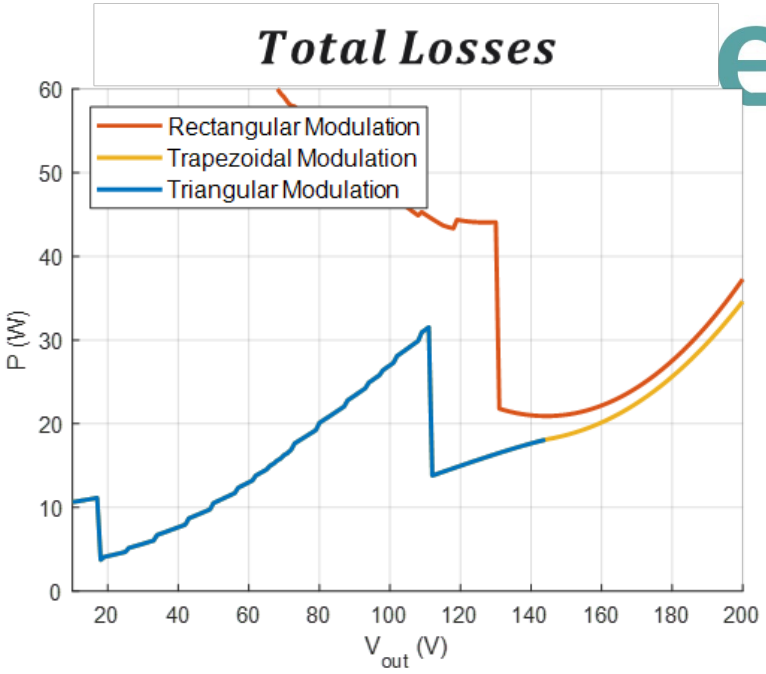
Dual Active Bridge

Different Modulations Compared

- Phase Shift/Rectangular
- Trapezoidal
- Triangular



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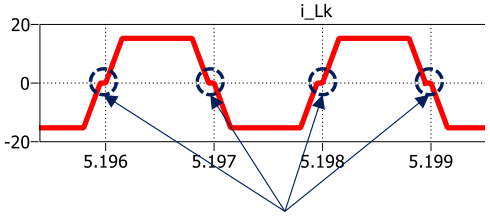
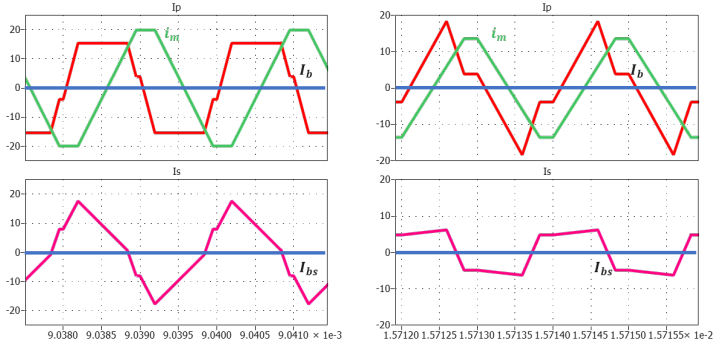
Classical trapezoidal modulation



No ZVS here

Modified trapezoidal and triangular modulation for ZVS



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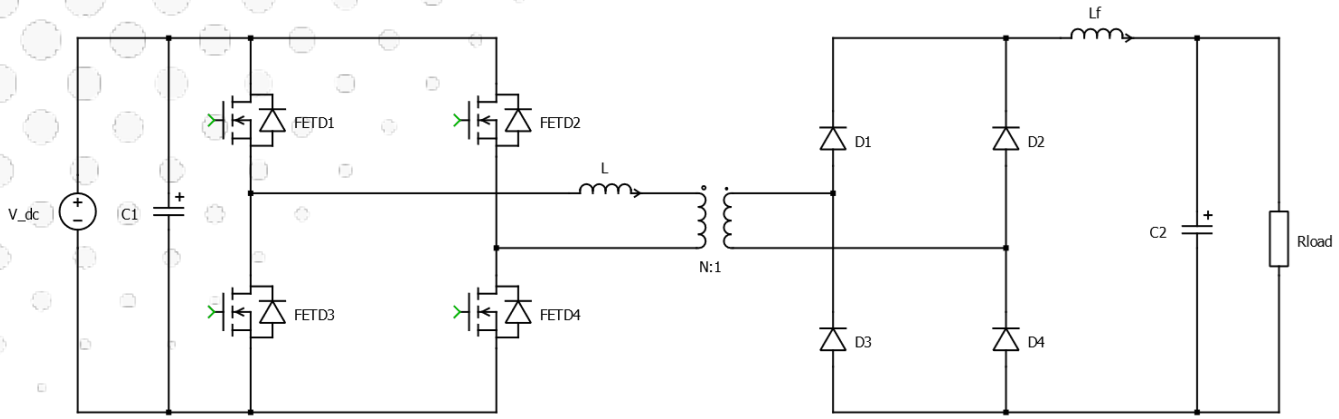
Phase Shift Full Bridge



Derated V_{ds} of the GaN limits the turns ratio design

$$0.4 < N < 0.5 \begin{cases} N = 3:7 \\ N = 4:9 \end{cases}$$

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	Nº GaN	Total Volume (cm^3)	Total Losses (W)
DAB with ZVS Modulation L=1uH N=1:2 L_m=2uH I_b=5.98A	12	24.90	35.60
Phase Shift Full Bridge L=0.5uH N=3:7 L_r=24uH	12	18.28	19.95

Phase Shift Full Bridge looks better compared to DAB…

→But duty cycle range is too close to the limits in both topologies

Regulation capability of both topologies is limited for this application

A different solution is needed

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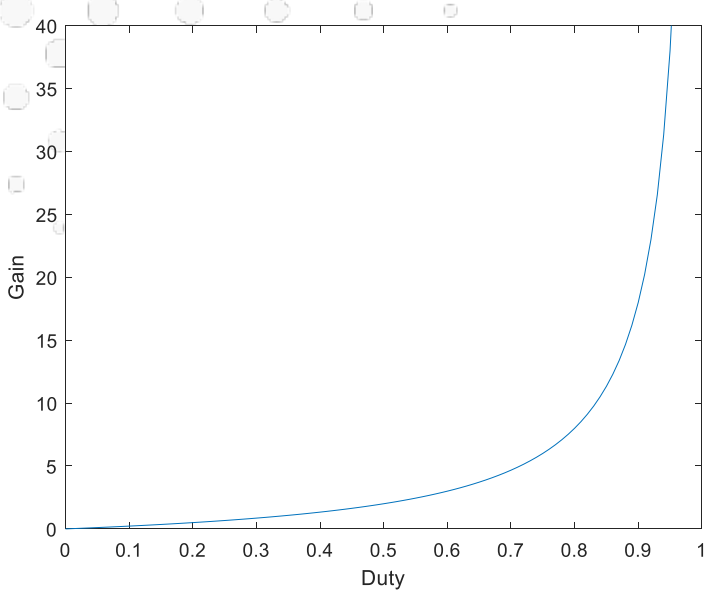
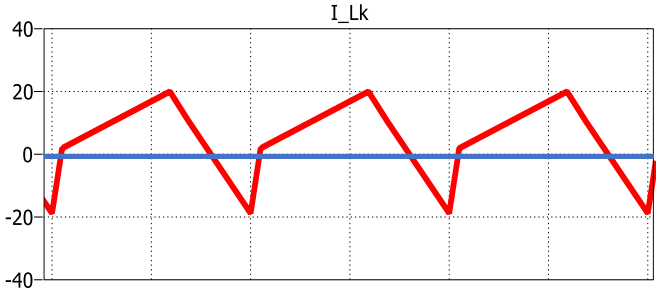
Flyback

$$\frac{V_{out}}{V_{in}} = \frac{1}{N}\frac{d}{1-d}$$

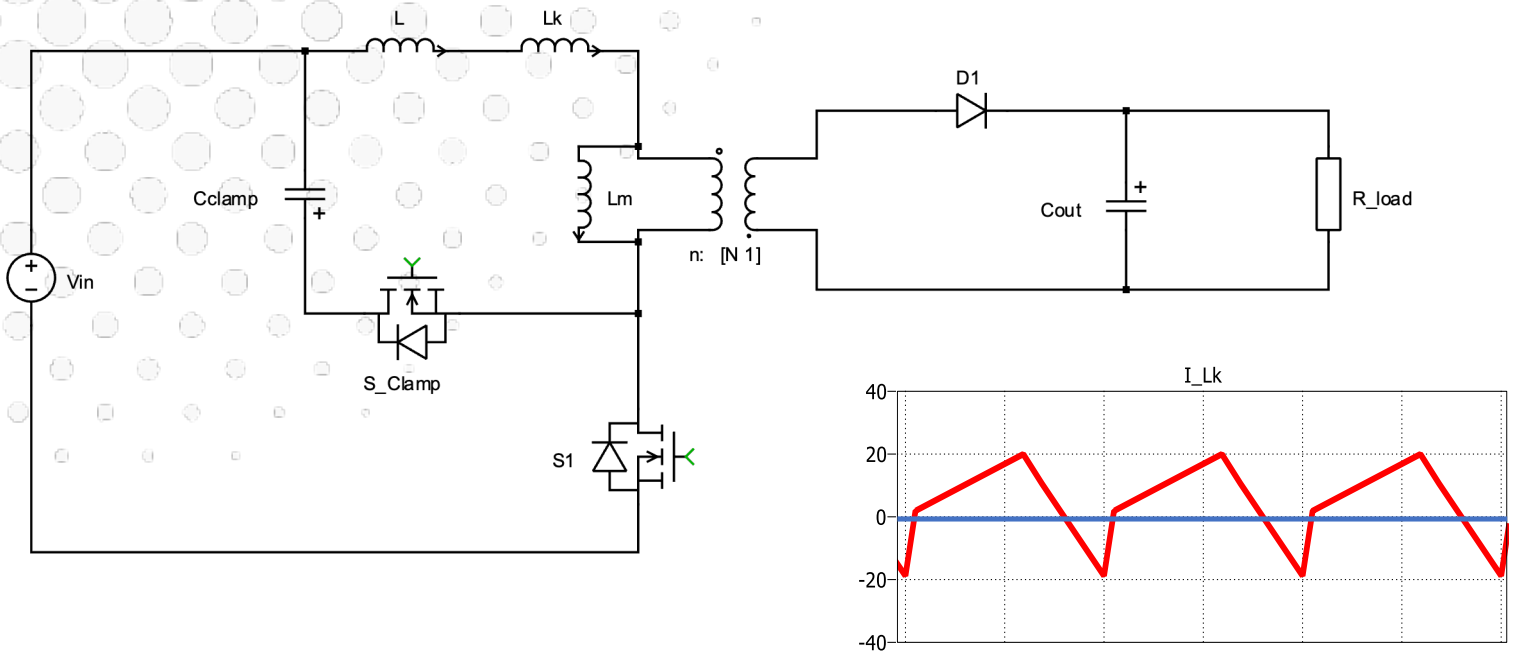
Advantage:
High regulation capability



Disadvantage:
High RMS current



Flyback with Active Clamp



ZVS achieved with added series inductor

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$$\boldsymbol{Primary}$$

$$V_{DS}^{Pri} = V_{in} + NV_{out}$$

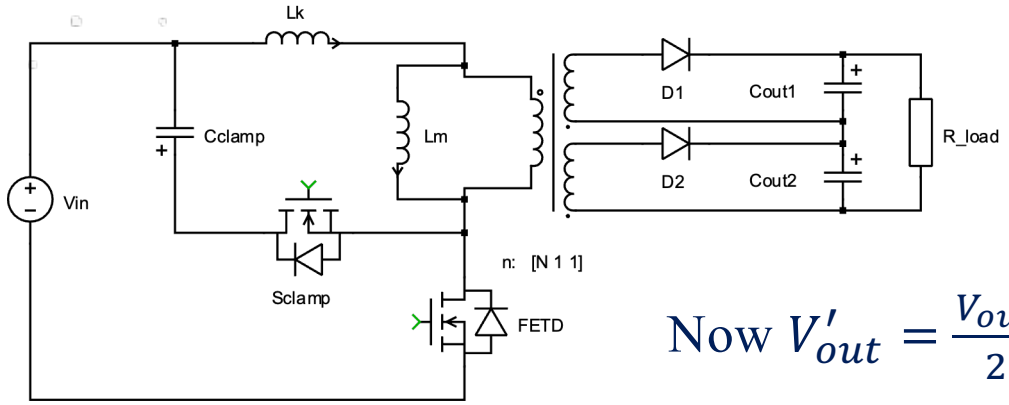
$$\boldsymbol{Secondary}$$

$$V_{DS}^{Sec} = \frac{V_{in}}{N} + V_{out}$$

No solution for the turns ratio

↓

Split the transformer secondary



Now $V'_{out} = \frac{V_{out}}{2}$

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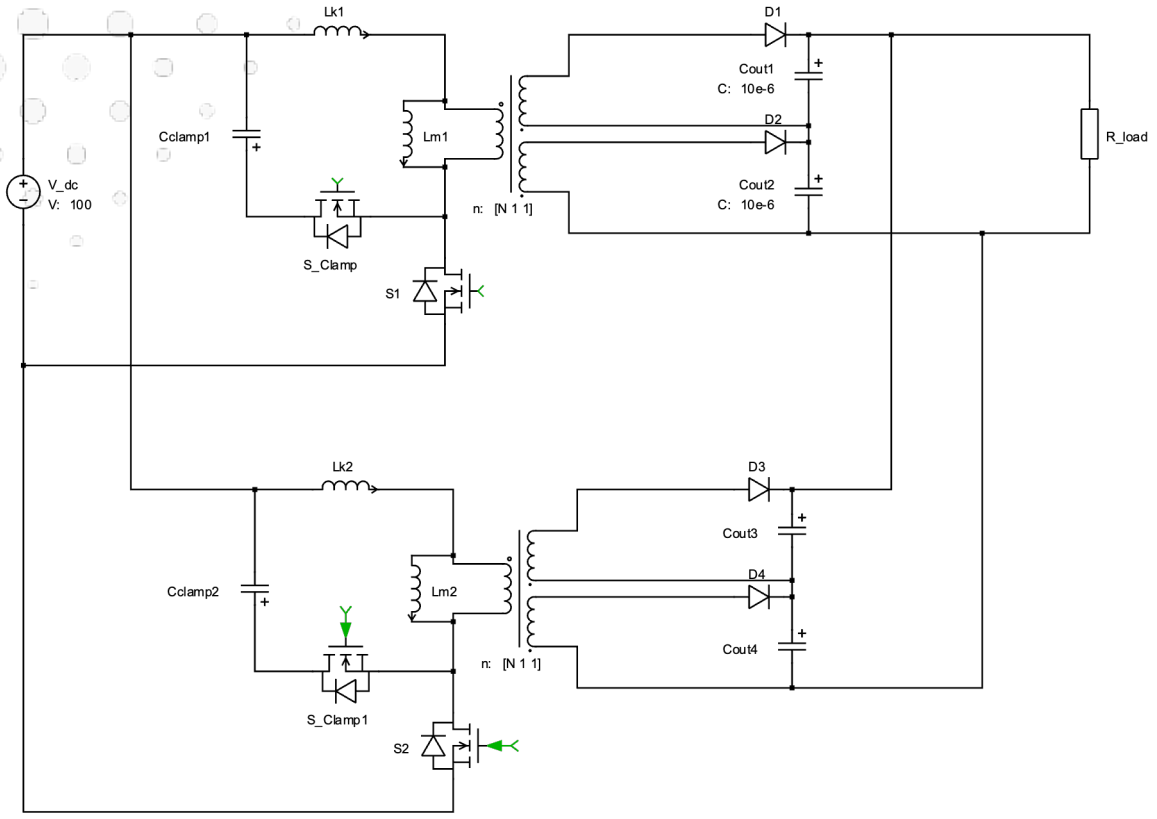
High RMS current → Parallelization Needed



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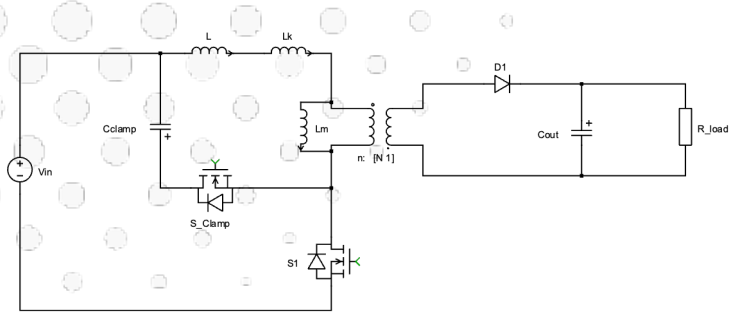
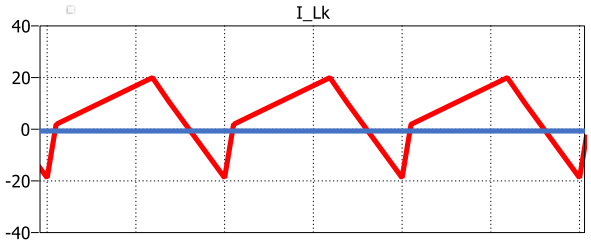
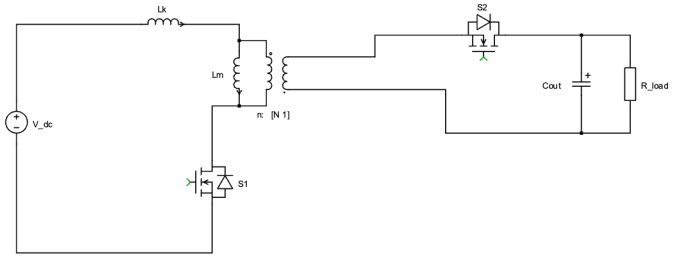
Active Clamp

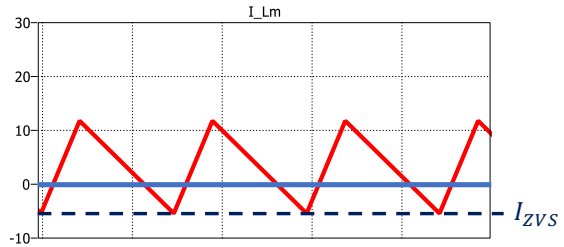




ZVS achieved with added series inductor

TCM Flyback





ZVS achieved with L_m varying the frequency

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	Nº GaN	Total Volume (cm^3)	Total Losses (W)
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Phase Shift Full Bridge L=0.5uH N=3:7 L_f=24uH	12	18.28	19.95
Active Clamp Flyback with series inductor **2 stages** **Parallel-Series** L=1uH N=1:1 L_m=5uH	8	55.20	42.42
TCM Flyback with variable fsw **2 stages** **Parallel-Parallel** N=1:1 L_m=2.6uH	8	46.40	62.72

Flyback takes up more volume but:

- Easily achieves the wide V_{out} range
- Needs less GaN devices

Leakage inductor energy to dissipate is too high

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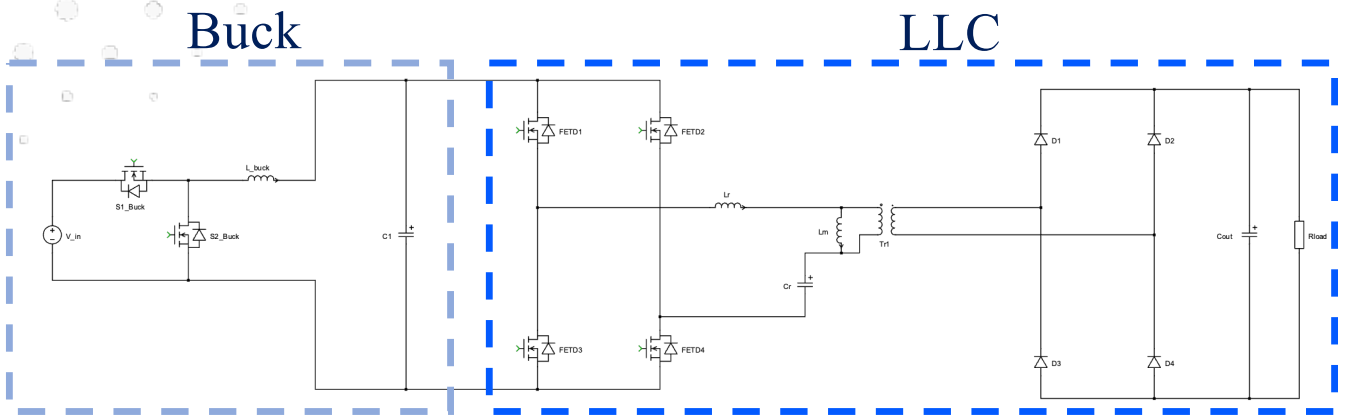
Two stages: regulator + DCx

Another way to achieve the wide V_{out} range?

→Use 2 topologies in series



Buck regulates the voltage range operating with ZVS
LLC provides isolation operating at the optimum resonant point

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Topologies Comparison

	Nº GaN	Total Volume (cm^3)	Total Losses (W)
DAB with ZVS Modulation L=1uH N=1:2 L_m=2uH I_b=5.98A	12	24.90	35.60
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TCM Flyback with variable fsw **2 stages** **Parallel-Parallel** N=1:1 L_m=2.6uH	8	46.40	62.72
Buck + LLC **2 Buck Stages** L_{buck}=2.94µH L_r=0.36µH C_r=277nF N=1:2 L_m=7.9µH	12	53.68	30.59

Smaller volume than flyback
Less losses than DAB

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Experimental Results

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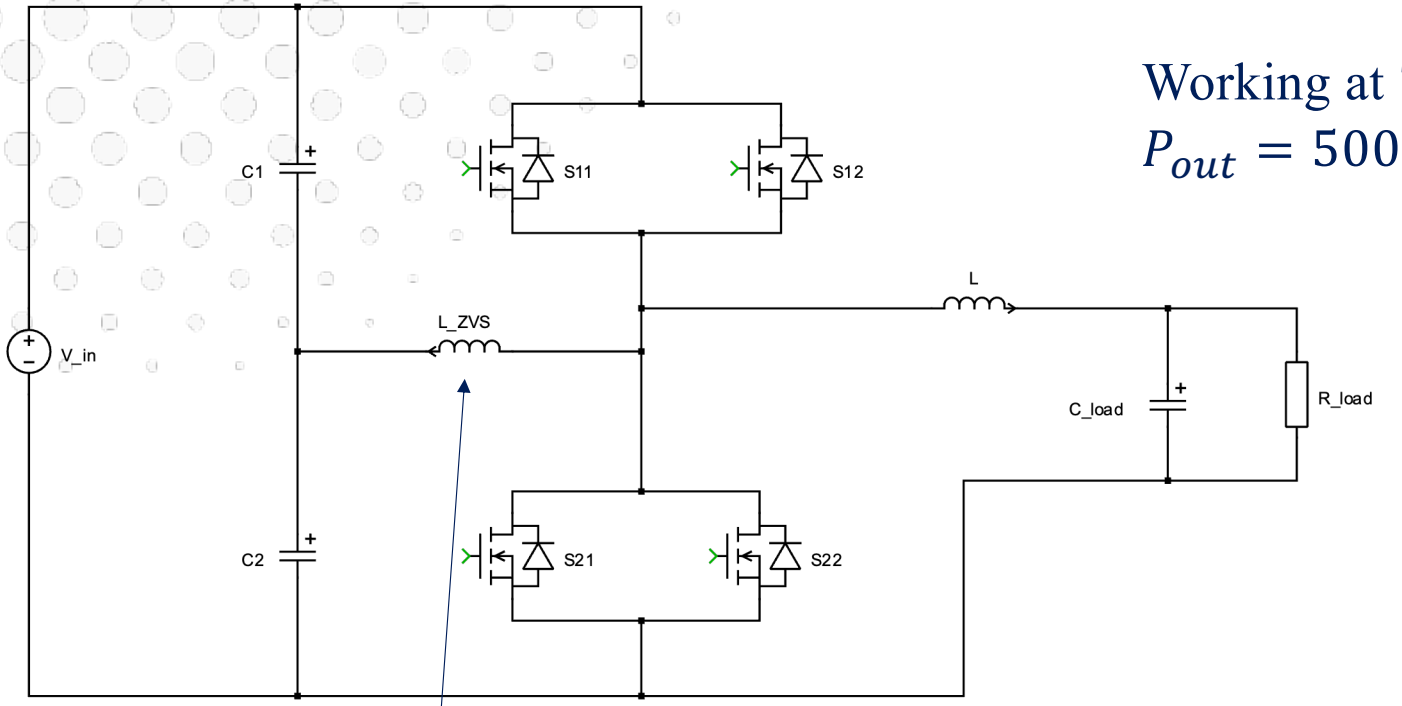
First prototype: Buck with ZVS inductor



Working at $700kHz$

$P_{out} = 500W$ at $V_{in} = 100V$

Additional inductor to achieve ZVS

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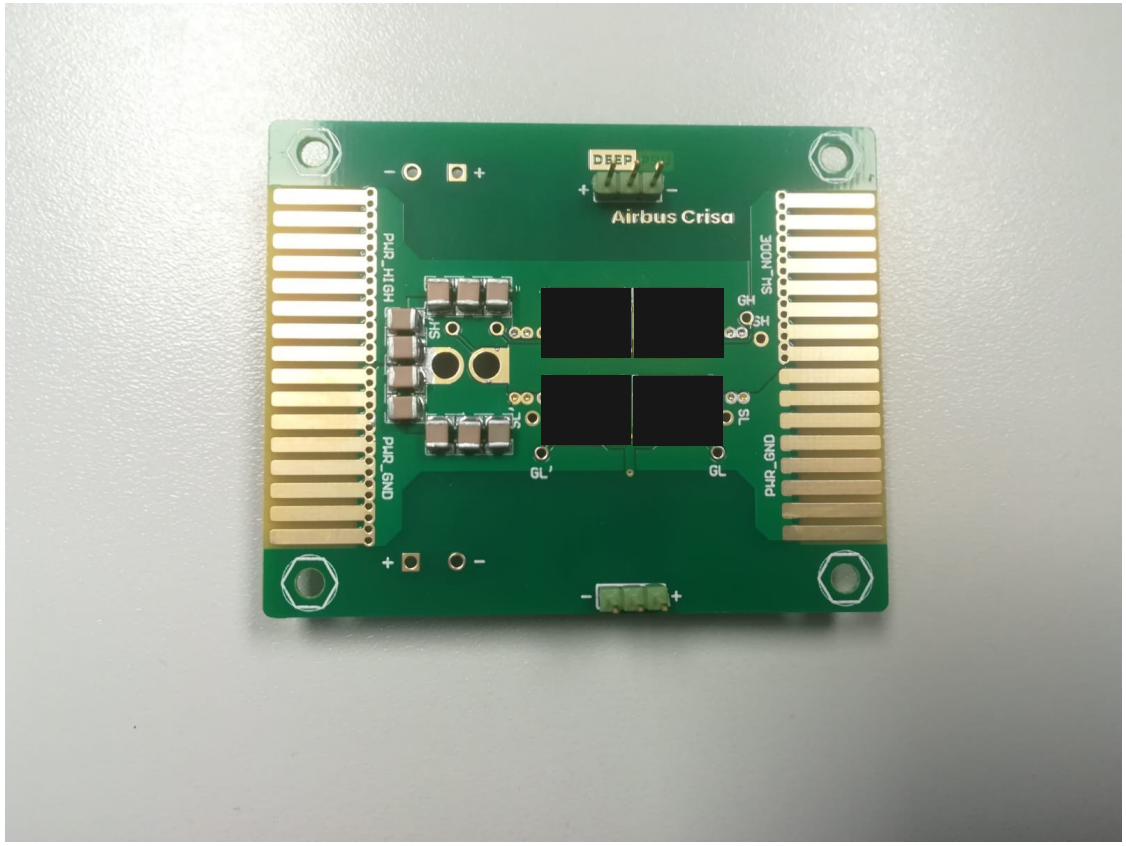
Prototype



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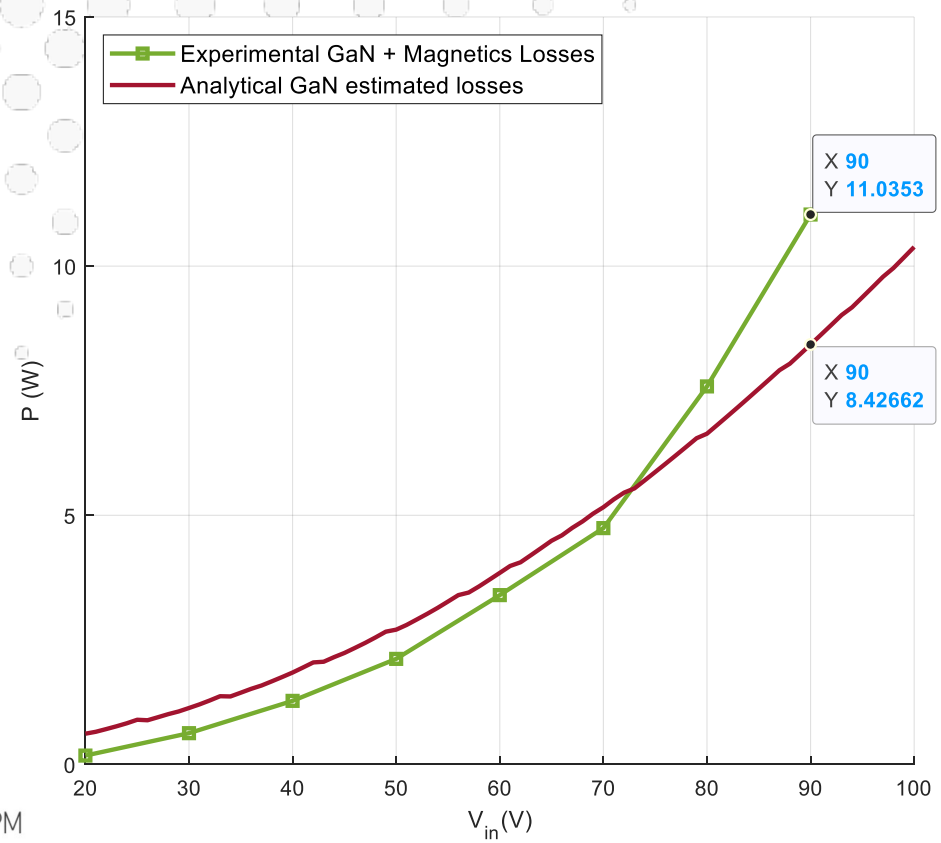
Experimental Losses Comparison



$\approx 2W$ of magnetics estimated losses @$V_{in} = 90V$

↓

Experimental GaN losses $\approx 9.035W@V_{in} = 90V$

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Conclusions

- High Regulation capability is needed
  - Several topologies discarded
- ZVS is critical to operate at high frequency
  - Even using GaN devices
- The two-stage approach is proposed
  - Buck, operating with ZVS, provides full regulation
  - LLC provides isolation at the optimum operating point

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Thank you

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