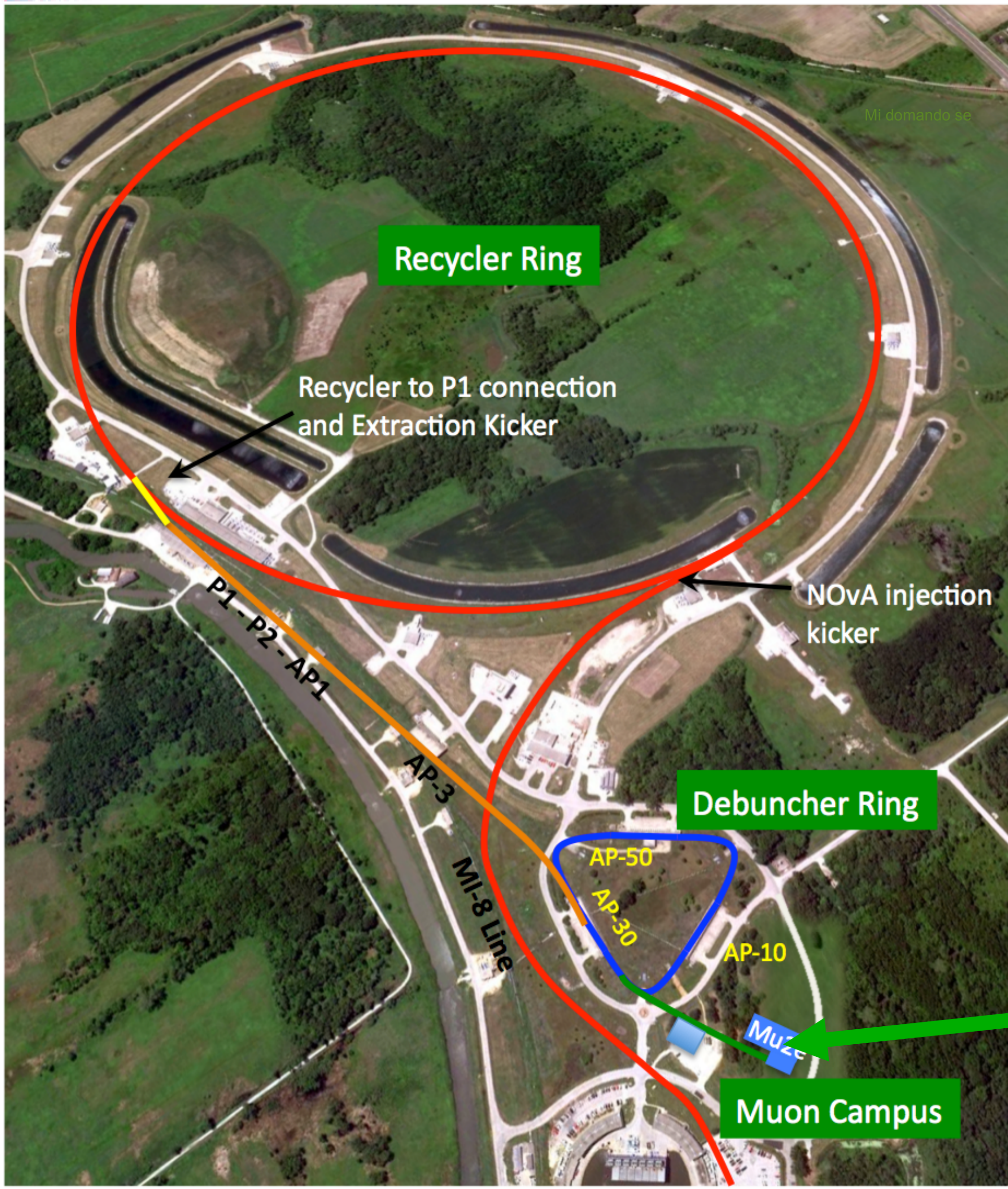
STUDY OF A POWER SUPPLY SYSTEM FOR THE DETECTORS IN MU2E EXPERIMENT

Fermilab summer project 2012

Daniele Ninci

26/09/2012

Mu2e experiment at Fermilab



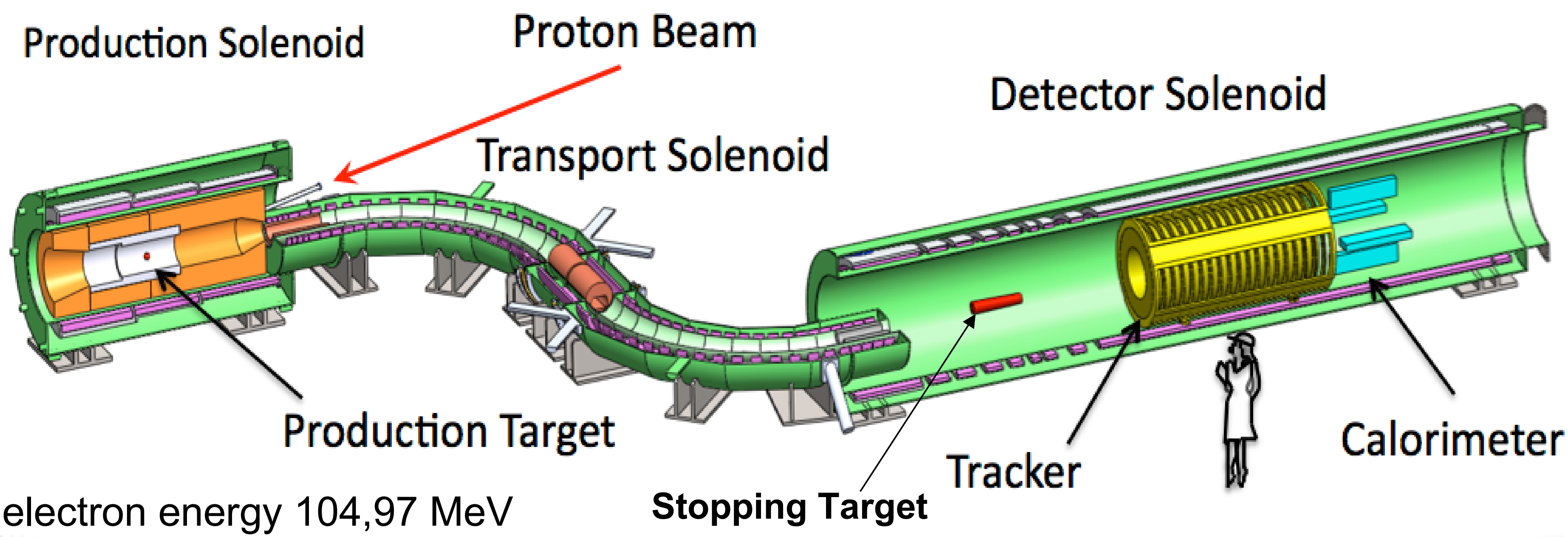
Searching for physics beyond Standard Model, charged lepton flavour violation (CLFV)

Measurement of the B.R. Of coherent conversion of muon into electron into a field of a nucleon, with a sensivity of $6{\cdot}10^{-17}$

$$R_{\mu e} = \frac{\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)}{\mu^- + A(Z,N) \rightarrow capture}$$

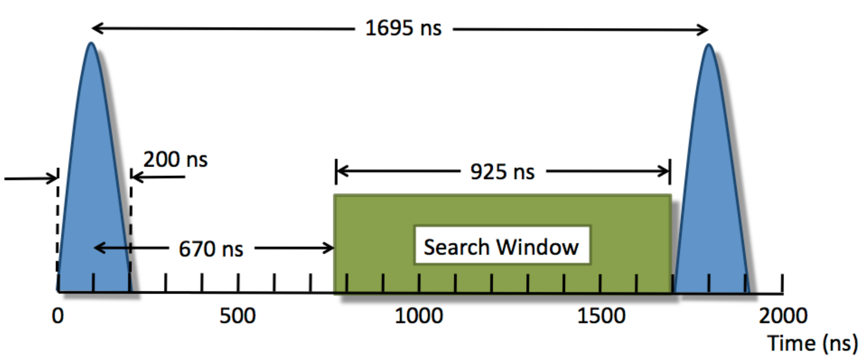
Mu2e site

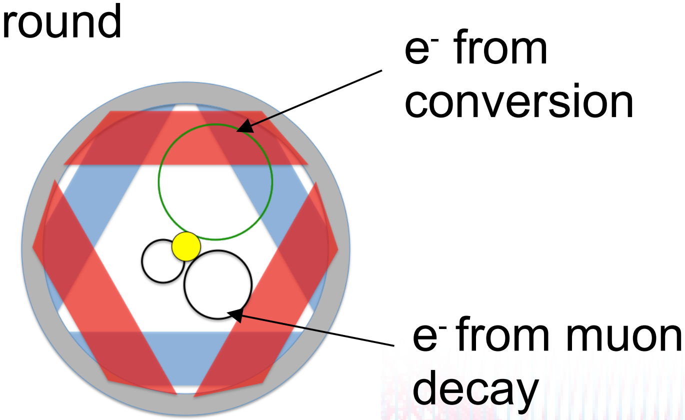
Experimental setup



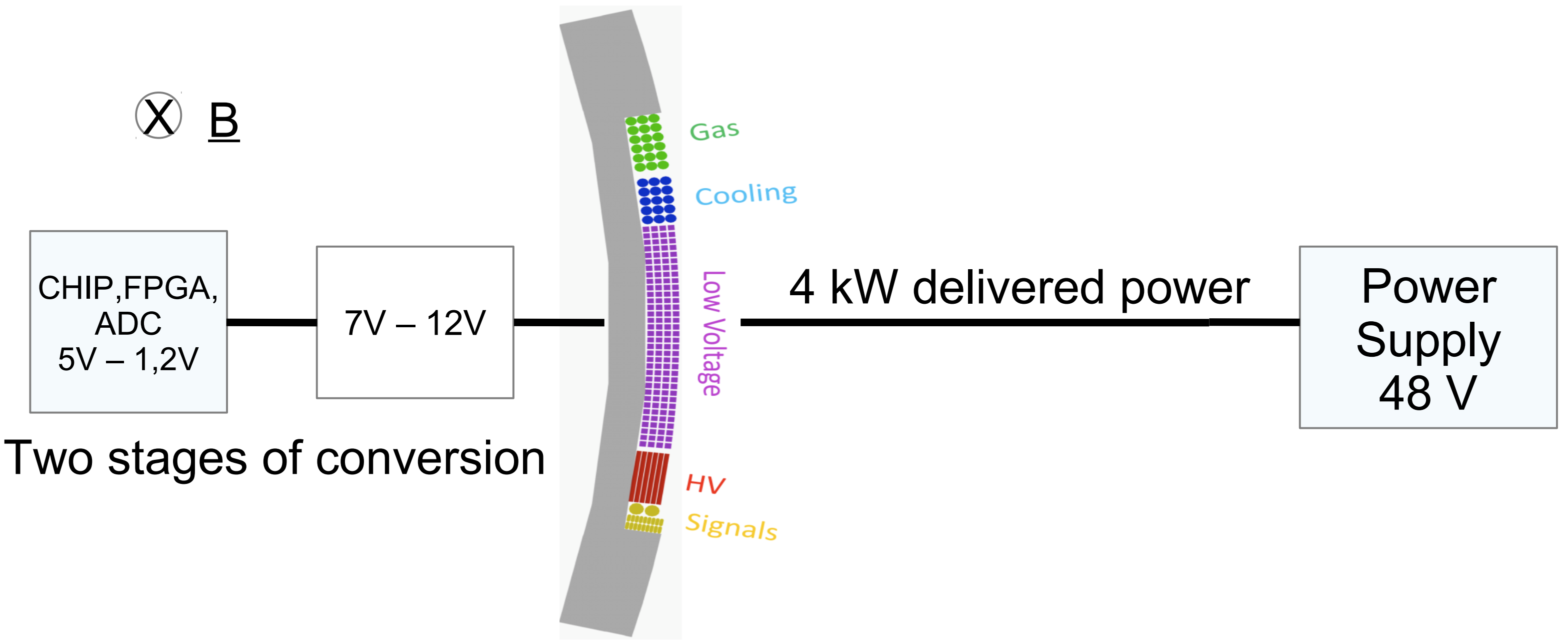
electron energy 104,97 MeV

Design made in order to suppress lots of the background





Power supply

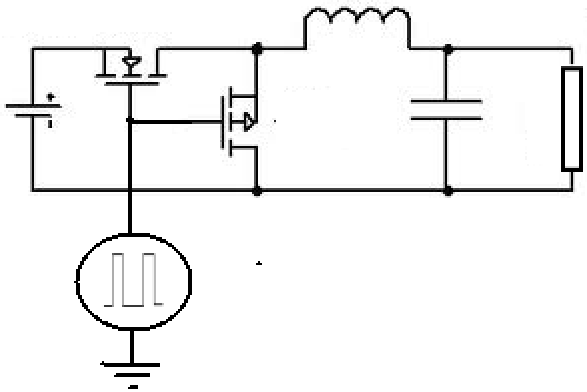


Linear converter (resistive)
-low EMI
-low efficiency (≈50%)
-large power dissipation
-large cable cross section
 and resistive losses

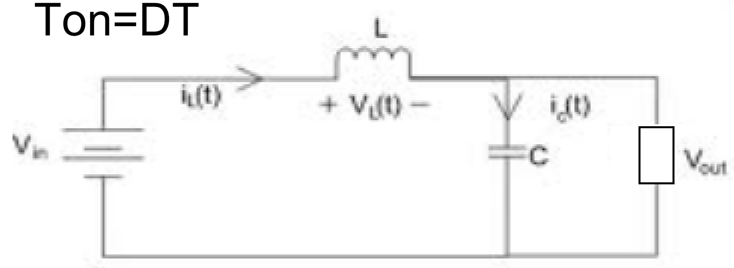
Switch mode dc-dc converter
-higher EMI
-higher efficiency (>70%)
-less power dissipation

dc-to-dc converter

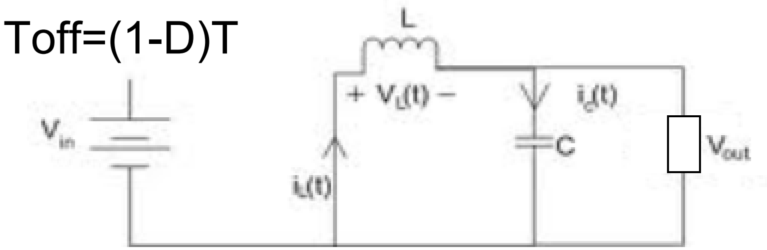
The energy is stored in the inductor and released to the load



Ton=DT



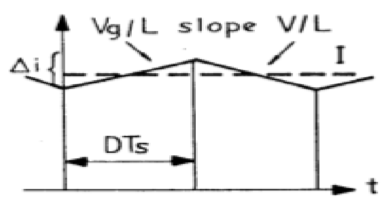
Toff=(1-D)T



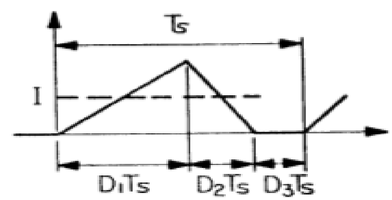
Vout depends on the Duty Cycle

i.e. in buck converter Vout=D*Vin

Continuos mode: $T_{off} > \tau_{dump}$



Discontinuos mode $T_{off} < \tau_{dump}$



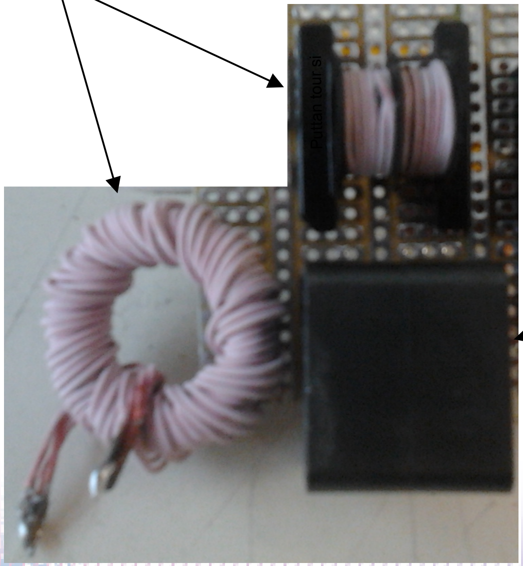
Power supply

Magnetic field in detector stage → inductor without ferromagnetic core to avoid saturation due to the ambient field.

⇩

Large inductor to recover the flux density lost due to the μ

Aircore inductors 1μH (>20turns)



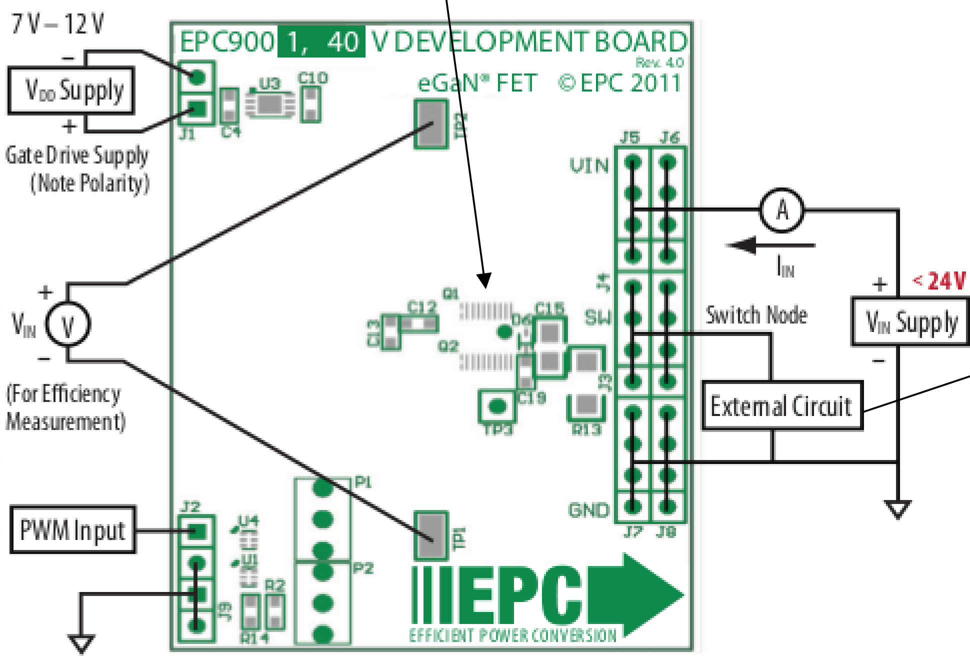
Large value of parasitic inductances and capacitances.

Ferromagnetic core 200μH (6 turns)

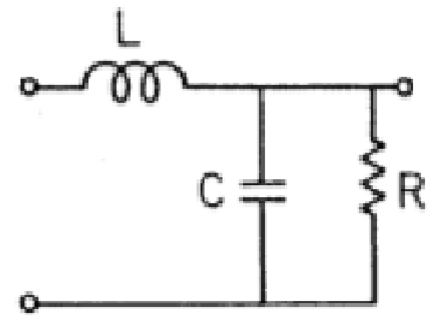
Final Conversion Stage

From 10 V to 1,5V - 5V

GaN transistors 2x4 mm



Buck converter
- simple implementation
- non-inverting output
- Vout = D*Vin



- R load = 0,3 Ω
- C = 33 μF
- L ≈ 1 μH

Resistance to high temperature
Work at higher voltage than Si transistor
Higer switching frequency
Radiation hard (Mrad)

Final Conversion Stage

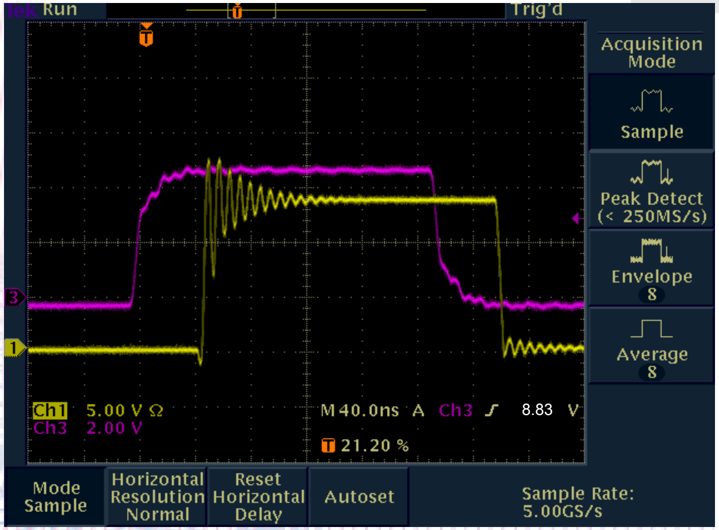
Buck converter solenoidal inductor (litz wire 24x36) efficiency results

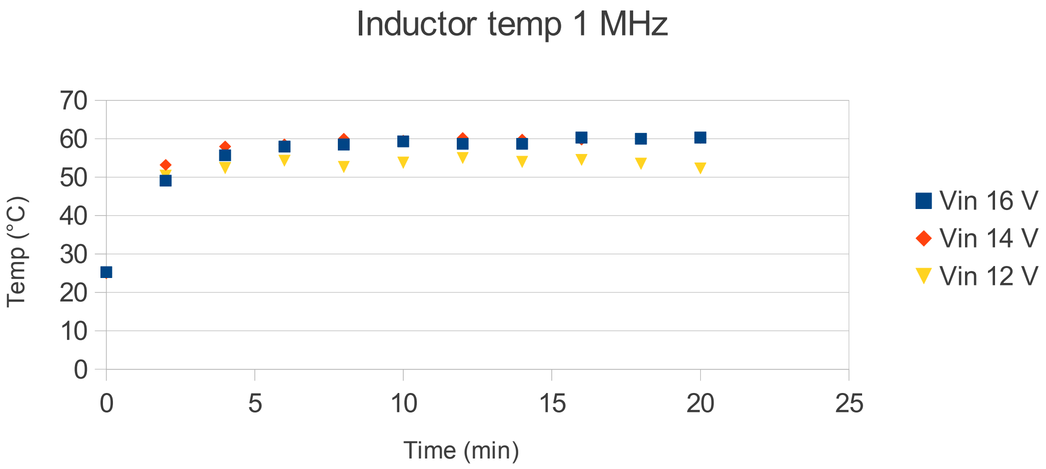
Vout/Vin ≈ D, neglecting parasitics resistances and losses during the switching.

Efficiency over 80%, expect higer with finer litz.

PWM and switch signal

Vin (V)	Freq (kHz)	D.C. (%)	Vout (V)	Eff (%)	RMS (%)
12	1000	14,4	1,490	84,5	0,4
	500	14,3	1,492	85,5	0,4
14	1000	12,3	1,488	83,0	0,4
	500	12,3	1,494	85,4	0,4
16	1000	10,9	1,501	82,4	0,4

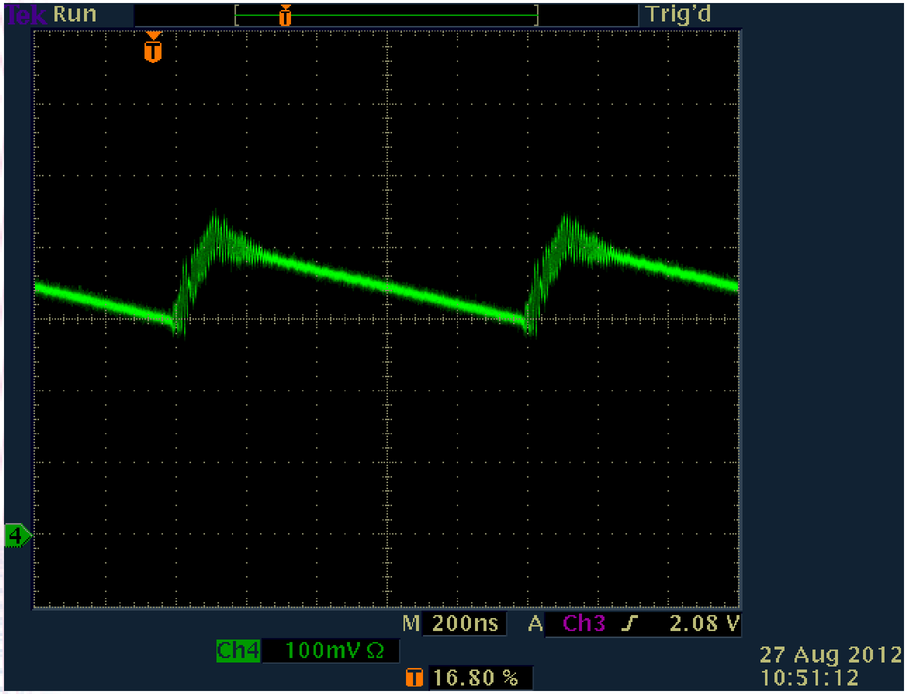




Final Conversion Stage

Trifiler toroidal inductor
Carry high current value dissipating less heat 7,78 A → T<48°
Decrease interaction with e.m. external field

Ripple current in inductor ~20% of signal



Vin	Freq	Eff (%)	RMS (%)
12	1MHz	81,0	0,4
12	1MHz	81,7	0,4
20	1MHz	81,5	0,4
24	1MHz	81,6	0,4

Initial Conversion Stage

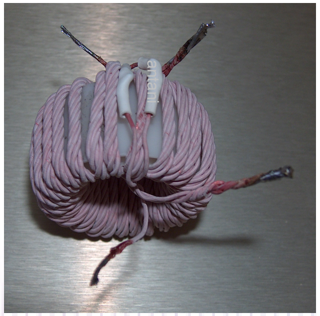
From 48 V to 10 V

Switch converter with transformer in resonant mode:

- working with 50% duty cycle at higer frequncy than buck converter
- isolation between power supply and load, preventing damage due to a transistor fault,
- negative or positive voltage supply,
- less EMI than buck converter.

Turns ratio 3:1

- $L_{primary}$ = 18,1 μH ; L_{leak} = 3,0 μH
- $L_{secondary}$ = 2,9 μH ; L_{leak} = 0,46 μH
- $C_{coupling}$ = 0,71 nF
- R = 0,1 - 0,3 Ω
- R_{ac} = 3,6 Ω (600kHz)
- ⌀ = 4 cm



Turns ratio 4:1

- $L_{primary}$ = 31,4 μH ; L_{leak} = 3,81 μH
- $L_{secondary}$ = 1,9 μH ; L_{leak} = 0,23 μH
- $C_{coupling}$ = 1,6 nF
- R = 0,1 - 0,3 Ω
- R_{ac} = 4,8 Ω (600kHz)
- ⌀ = 4 cm

Initial Conversion Stage

Resonant capacitance: 13 nF
Silicon instead of the GaN mosfet

Resonance frequency ≈ 500 kHz

Without rectification

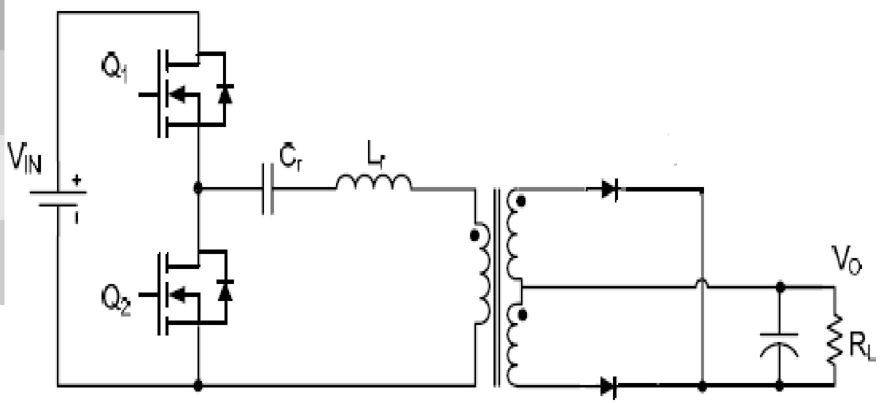
3:1

F(kHz)	Vin (V)	Vout (V)	Eff(%)	RMS (%)
600	48	7,00	80,0	0,5
700	48	7,64	84,2	0,5
800	48	6,08	74,4	0,5

4:1

F(kHz)	Vin (V)	Vout (V)	Eff (%)	RMS (%)
500	48	5,8	83,4	0,7
600	48	5,16	82,2	0,8
700	48	4,48	79,5	1,0
760	48	4,24	82,4	1,0

With half bridge diodes rectification

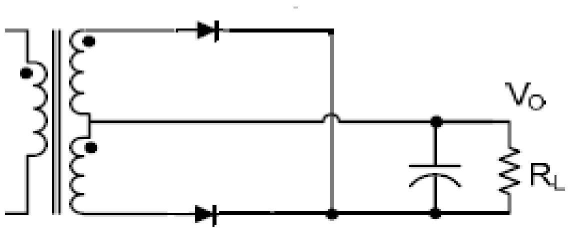


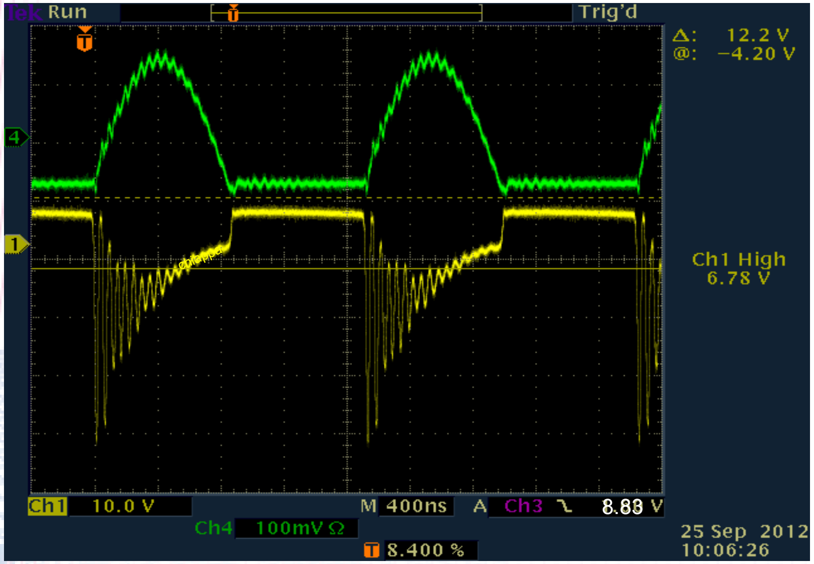
F(kHz)	Vin (V)	Vout (V)	Eff (%)	RMS (%)
480	48	5,74	70,7	0,5
600	48	5,38	74,3	0,7
700	48	4,94	74,8	0,7
800	48	4,52	73,1	0,8

Initial Conversion Stage

Significant ringing on the diode anodes

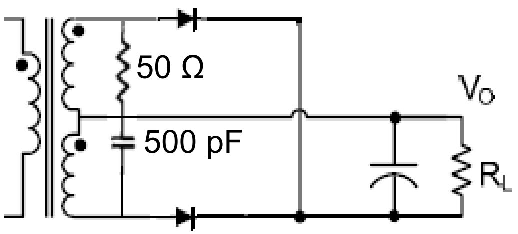
Efficiency 74% @ 600kHz

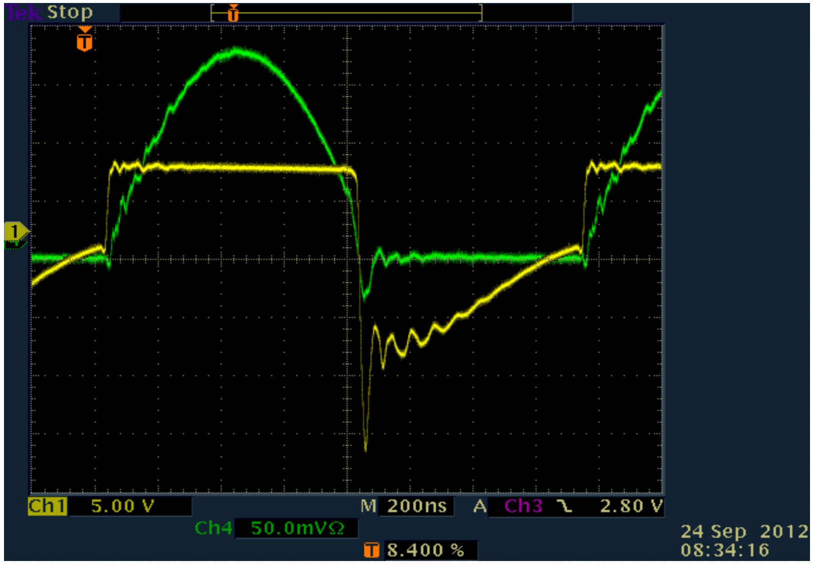




Ringing reduced by adding a snubber.

Efficiency 76% @ 600kHz





Initial Conversion Stage

Using a finer litz wire (660x45) is possible to reduce AC resistance and increase in efficiency

4:1 transormer fine litz wire

- $L_{primary}$ = 7,02 µH ; L_{leak} = 3,2 µH
- $L_{secondary}$ = 0,88 µH ;
- $C_{coupling}$ = 0,2 nF
- R = 0,2 Ω
- ⌀ = 5 cm

Tested with a resonant capacitance of 13 nF

Freq (kHz)	Vin (V)	Vout (V)	Iout (A)	Pout (W)	Eff (%)	RMS (%)
790	48	8,5	4,25	36,125	81,5	0,2
850	48	7	3,5	24,5	83,0	0,3

Conclusions

- buck converter is a good choice for a final stage;
- rectification with diodes cause a drop in efficiency;
- aircore transformers appear to be promising for the first level converters.

Future plans

- implementation of half bridge and full bridge converters with synchronous rectification;
- optimization of transformer;
- introduce closed loop operation;
- test the interaction between the two stages of converter;
- measure EMI.

THANK YOU