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Where power supply design meets collaboration

Very high voltage AC-DC power: From 3-phase to single phase offline bias supplies

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What will I get out of this session?

- Purpose:
  - Design Considerations for low power bias supplies from 3-phase inputs.
  - Configurations to meet the bulk cap and switch voltage rating.

- Part numbers mentioned:

  UCC2872x, UCC2891x, UCC2870x, UCC2871x, UCC2888x, UCC28C4x, LM5021

- Reference designs mentioned:

  PMP11236 PMP10937 PMP10834
  PMP7769 PMP10415 TIDA-00628
  PMP8678 TIDA-00173 PMP11302

- Relevant End Equipment:

  E-Meters, Industrial Power Supplies

Agenda

- High voltage background
  - Why so high, what are the implications?
- Bias supplies and high voltages
  - Why are they needed, what topologies can be used?
- Bulk capacitor considerations
- Switch rating considerations
- Conclusions

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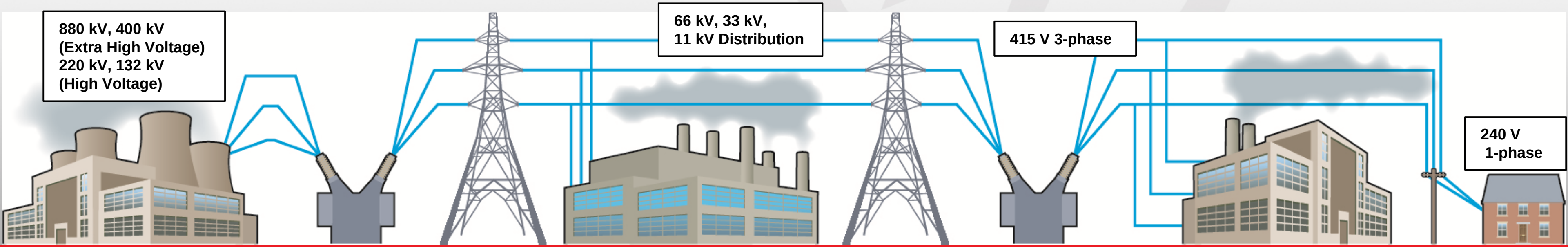
Power distribution grid

- Power distribution at very high voltage – reduced currents & losses; lower cost & weight infrastructure
- Three-phase distribution – allows constant power transfer; lower rms currents
- High kV distribution voltage – down-converted at local distribution transformer.
    - Single phases tapped off for domestic use at ~120/240 V ac
    - High power loads supplied with 3-phase



Three phase supply voltages


- Three phase voltage is typically 400 V ac in Europe and 210-270 V ac in the US
- Voltage levels vary considerably by region, by configuration and by application
- Voltage ranges of 525-600 V ac or up to 690 V ac are sometimes encountered

Three phase loads


- Three-phase induction motors, industrial motor drives
- High power heating and welding equipment
- High power UPS for Data centers
- High voltage EV chargers
- E-meters – sometimes three-phase rated to withstand mistaken phase-phase wiring

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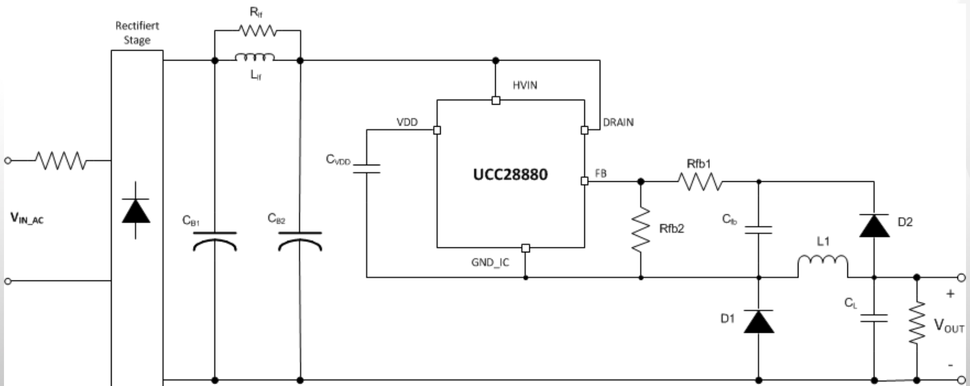
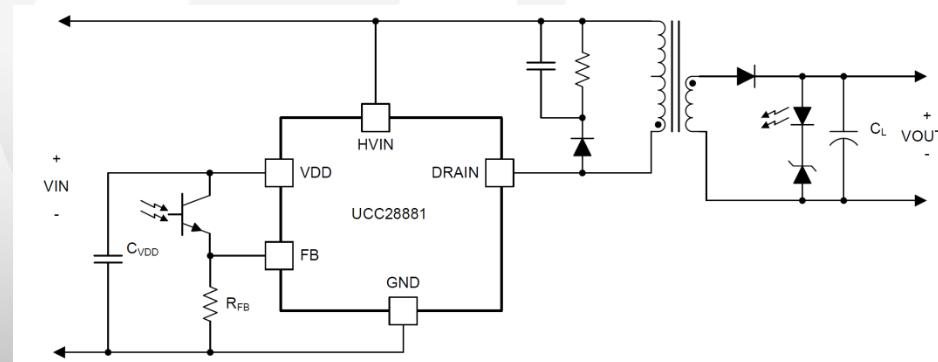
Auxiliary bias supplies for three-phase input voltages

- Require bias power at low voltages to power controllers, gate drivers, CPUs etc.
- High input voltage => require physically larger and more expensive components
  - Since power is low, large & costly bias supply becomes unpalatable for customers
- Principal design requirements:
  - Robust and reliable
  - Low cost
  - Low EMI and low noise
  - Easy to design & develop.
- Secondary considerations:
  - Efficiency & thermal performance
  - Regulation & cross-regulation accuracy
  - Size
  - Fault response

High-voltage bias supplies topologies

- Most common approaches:
  - Non-isolated outputs: HV Buck or Flyback
  - Isolated outputs: Flyback





Most significant components for high-voltage ***– bulk capacitors and the power switch.***

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Low power, non-isolated integrated buck

- UCC28880/1 – 700-V integrated switchers [*different Rds(on)*]
- Can be used in buck configuration up to ~450 V ac input line
- E.g. PMP11236 dual 24-V & 5-V outputs
- Can be deployed in high-side or low-side
- Can be used in non-isolated Flyback for higher power

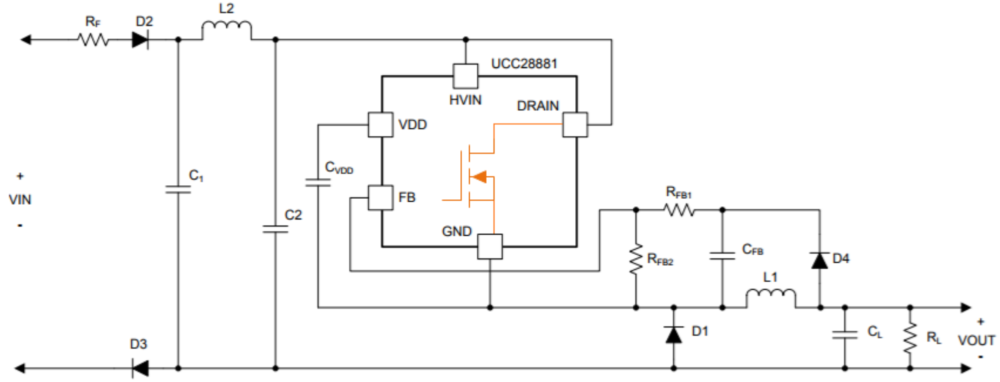


Figure 16. Universal Input, 12-V, 225-mA Output High-Side Buck

Power Handling Capability with Different Topologies

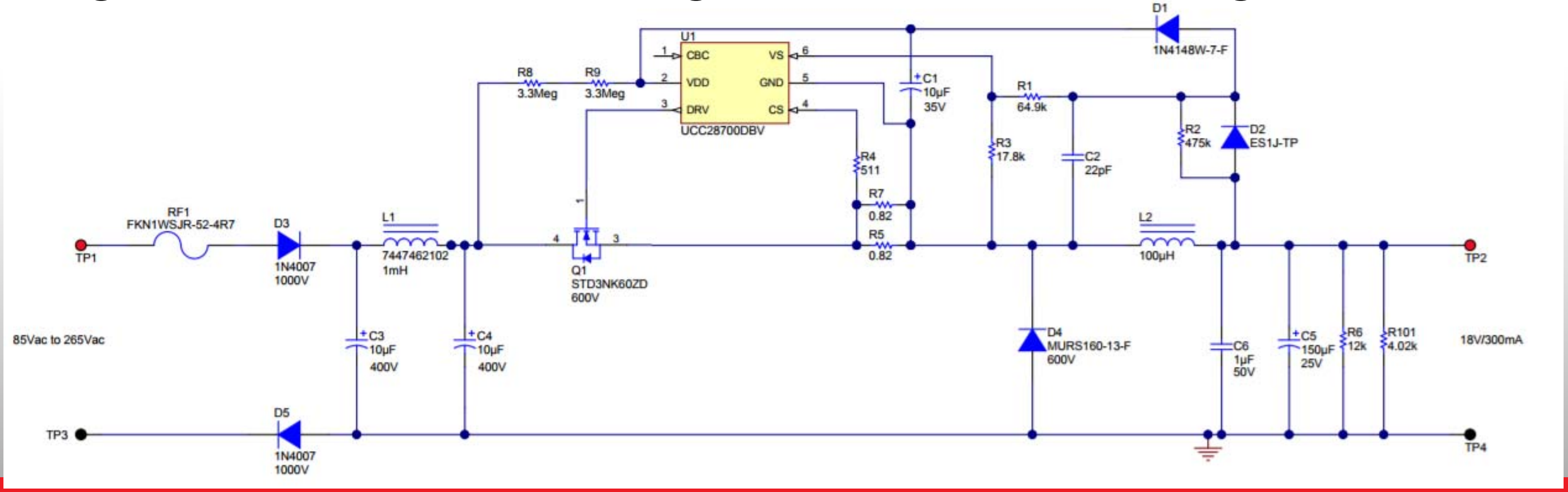
PRODUCT	MAXIMUM OUTPUT CURRENT for 85 ~ 265 VAC OPEN FRAME DESIGN	MAXIMUM OUTPUT POWER for 85 ~ 265 VAC OPEN FRAME DESIGN
	NON-ISOLATED BUCK	FLYBACK
UCC28880	100 mA	3 W
UCC28881	225 mA	4.5 W

Table 1. Current Handling Capability for UCC28880 and UCC28881

DEVICE	CURRENT HANDLING MODE	230 V_{AC} ±15%	85 V ~ 265 V_{AC}
UCC28881	Discontinuous Conduction Mode (DCM)	150 mA	150 mA
UCC28881	Continuous Conduction Mode (CCM)	225 mA	225 mA
UCC28880	Discontinuous Conduction Mode (DCM)	70 mA	70 mA
UCC28880	Continuous Conduction Mode (CCM)	100 mA	100 mA

Low power, non-isolated buck with external FET

- External FET controlled by PWM IC for higher current & wider Vin/Vout range
- UCC287xx or UCC28C4x families can be used with external FET, e.g. PMP10937
- D2/C2 generates level-shifted FB signal – tradeoff no-load regulation vs burst freq



Low power isolated bias supply – Flyback

- For isolation, Flyback is near-universal choice
  - Only requires single magnetic for both isolation and voltage conversion
- Inherently better-suited to wide input range
  - Disadvantage – peak switch voltage is higher than the input voltage.
- For universal input range (90-264 V ac), 650-700V switch is typical
- For 440 V ac, switch rating > 1kV is required
  - Unless the bulk cap voltage is clamped or reduced in some way

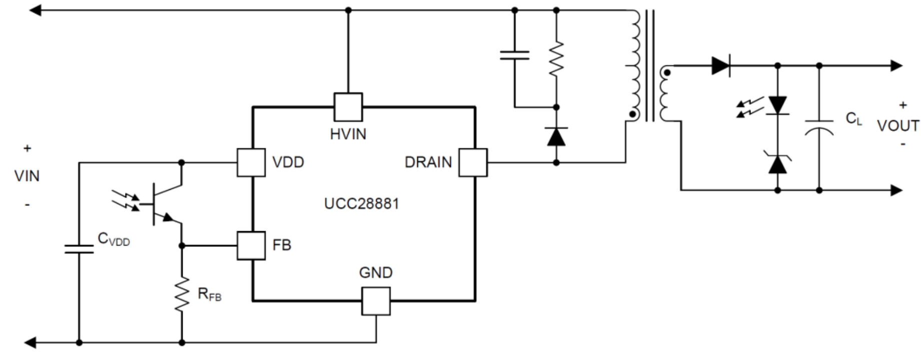


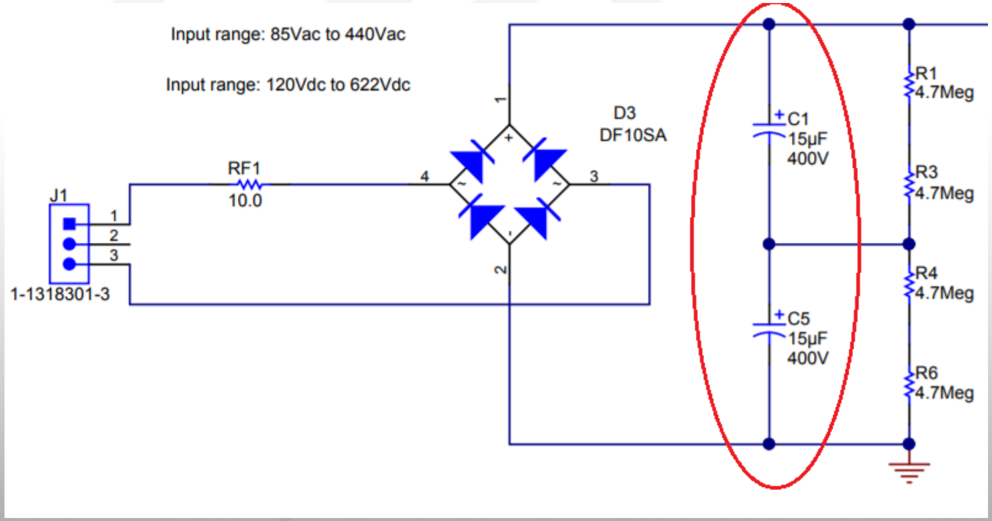
Figure 25. Isolated Flyback Converter

Bulk capacitors

- Necessary for energy storage & filtering of 50-Hz AC voltage
- Aluminium electrolytics : high volumetric efficiency relative to other capacitor types
- Despite low cost vs other capacitor types, still quite expensive – big % of BOM cost
- Single-phase mains 240 V ac + 10% tolerance -> 373 V peak =>
  - Wide range of 400-V aluminum electrolytic caps available
  - At > 450-V aluminium electrolytics become expensive
  - Capacitance values required for 1-W to 100-W levels not generally available above 600 V
- How to cope with high bus voltage up to 1 kV? Several possible methods

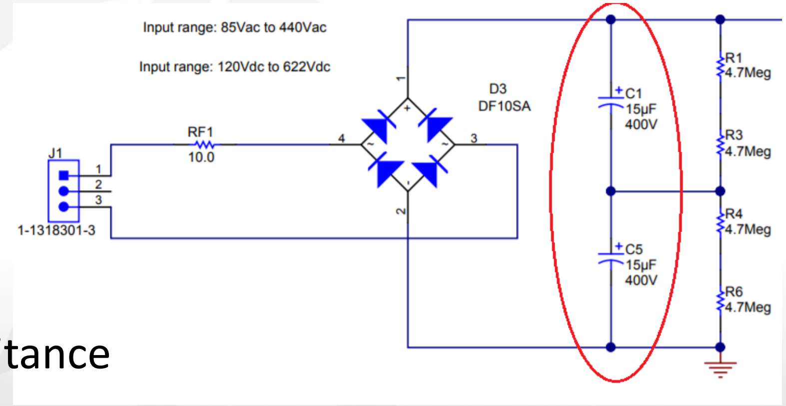
Bulk capacitors for high bus voltage – connect in series

- Extra bulk caps connected in series to meet required voltage rating
- Most common approach
- Example here from PMP10236
- Here max AC input 440 V ac, peak equivalent to 622 V dc
- Two 400-V caps stacked in series to achieve required rating



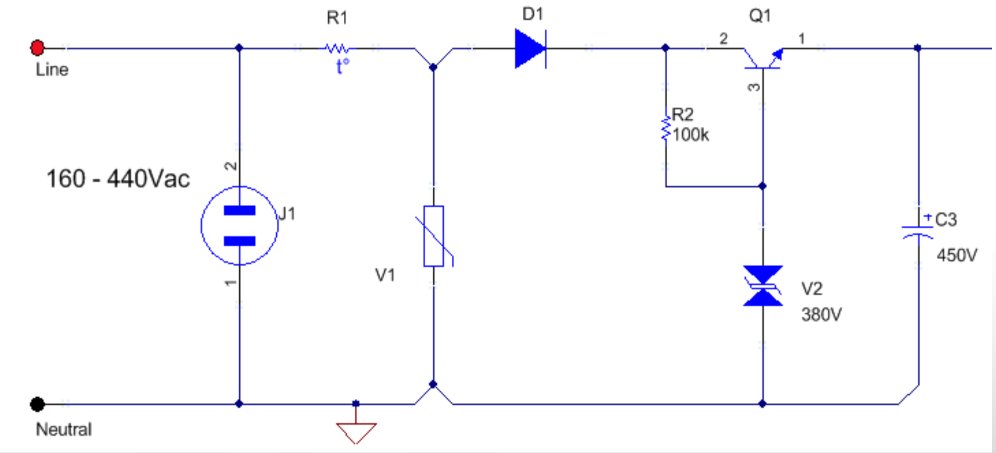
Bulk capacitors for high bus voltage – connect in series

- Advantages
  - Robust and reliable
  - Simple implementation
  - Re-use existing 400-V rated caps
- Disadvantages
  - More caps required to achieve required capacitance
    - Expensive, bulky
  - Balancing resistors required to ensure that voltage divides equally across caps
    - Extra dissipation, PCB area and cost
    - Balancing current must be >> cap leakage current



Limit high bus voltage – add input clamp/regulator

- TVS diode sets clamp voltage
- BJT transistor drops the excess voltage
- Clips the voltage to the bulk cap
- BJT limited by base current and R2 value, causes line-dependent clamp
    - See appendix slide for more detail
- At higher power (> ~3 W), MOSFET may be required instead of BJT



- Disadvantage – high voltage MOSFETs are more expensive than high voltage BJTs.

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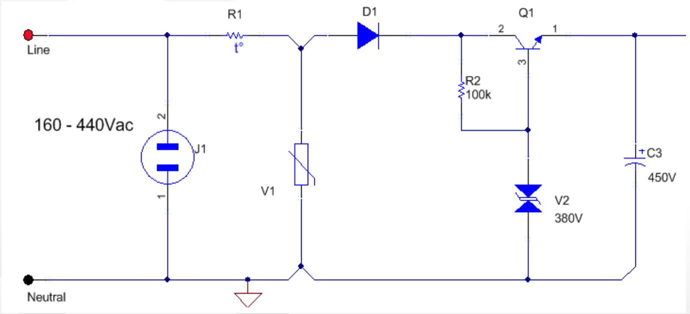
Limit high bus voltage – add input clamp/regulator

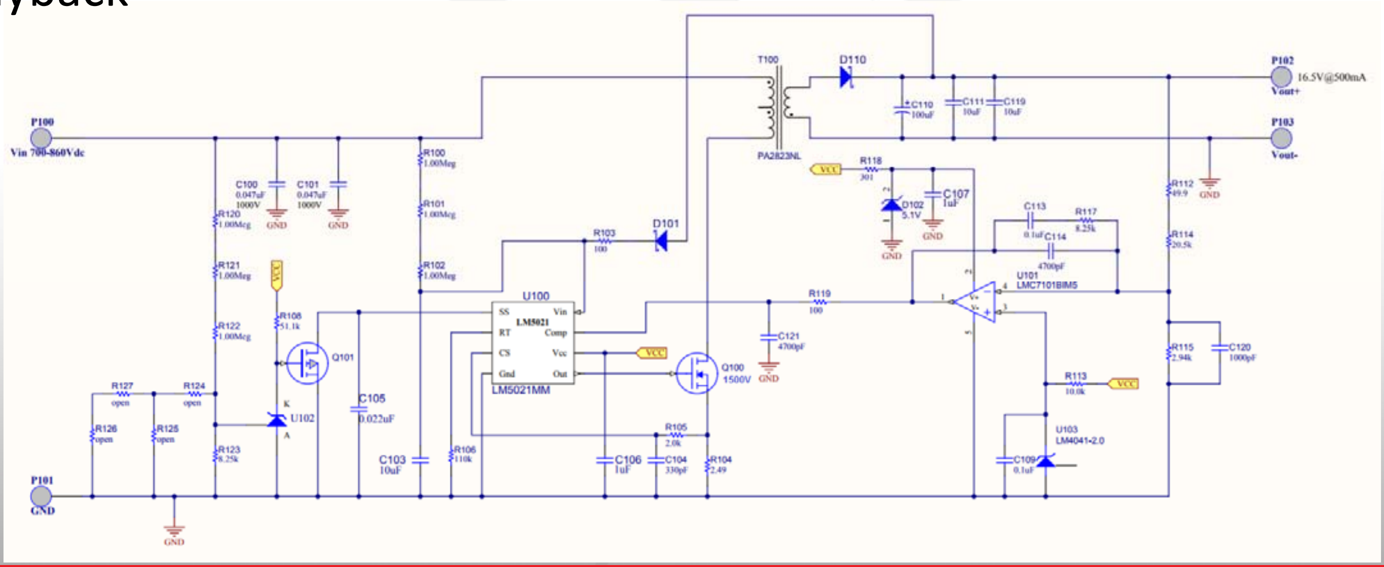
- Advantages
  - Smaller solution size vs extra bulk capacitance
  - Lower cost solution, (BJT + R + TVS) vs bulk cap
  - Allows lower voltage-rating power switch
  - Effective for short-term line surges



- Disadvantage
  - Limited in power capability if using BJT; MOSFET solution adds cost
  - Can suffer high clamp dissipation if operated continuously at high line

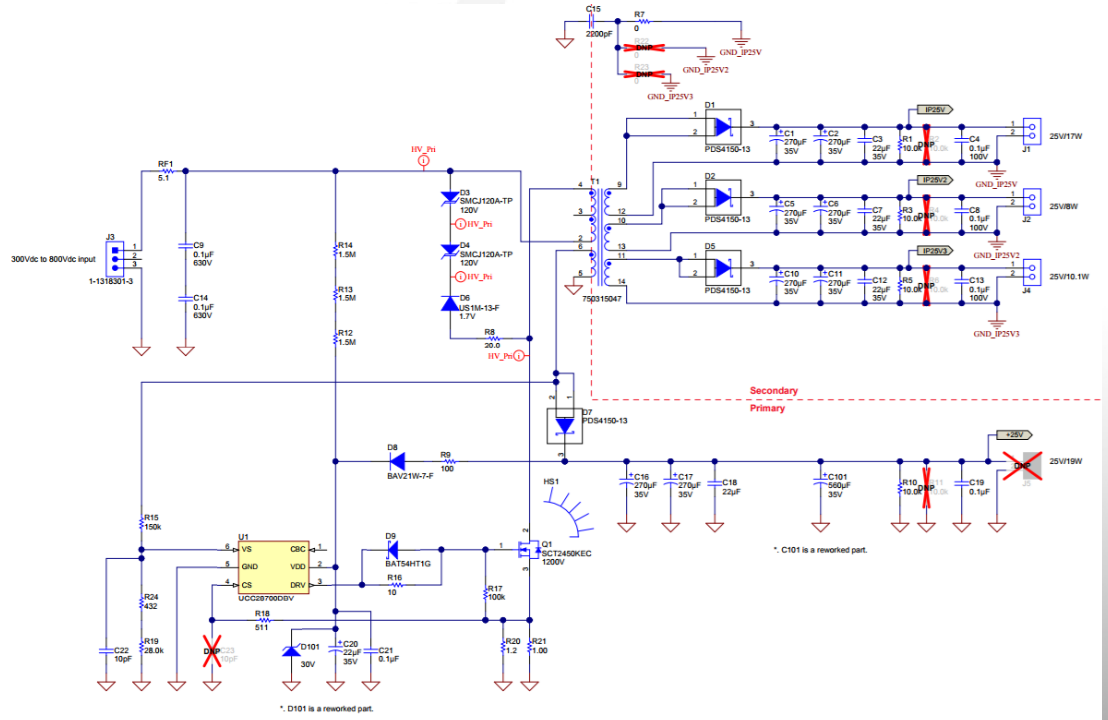
High voltage power switch – single switch options

- Simplest solution – use a single high voltage Si FET
- E.g. PMP7769 8-W Flyback
- 860 V dc max Vin
- LM5021-based fixed-frequency
- 1.5-kV Si MOSFET STP3N150 6-ohm
- But SiC FETs getting cost competitive…



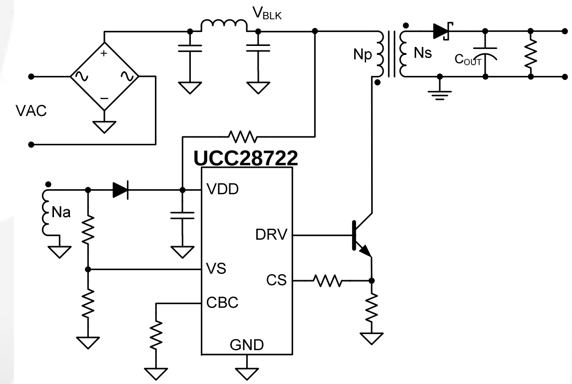
High voltage power switch – SiC switch options

- E.g. PMP10415 54-W Flyback
- Multi-output Flyback
- Based on UCC28700
- Uses 1.2-kV Silicon Carbide MOSFET
    - Rohm SCT2450KEC 0.45-ohm



High voltage power switch – BJT switch options

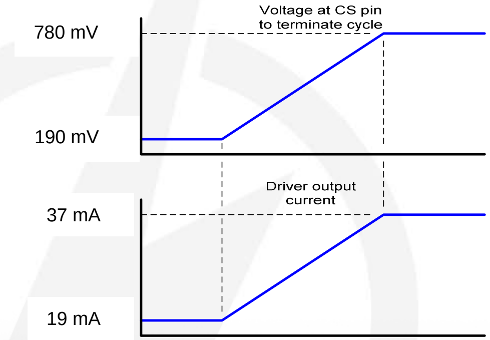
- Low cost option – high voltage BJTs
  - Less expensive than high voltage MOSFETs
- BJTs are current-controlled – more complex drive requirements compared to MOSFETs
- Excess base current => saturation & very slow turn off
- Proportional drive
  - Modulates base current, proportional to load
  - Light load – base not driven with excess current vs collector current, improves switching speed & efficiency

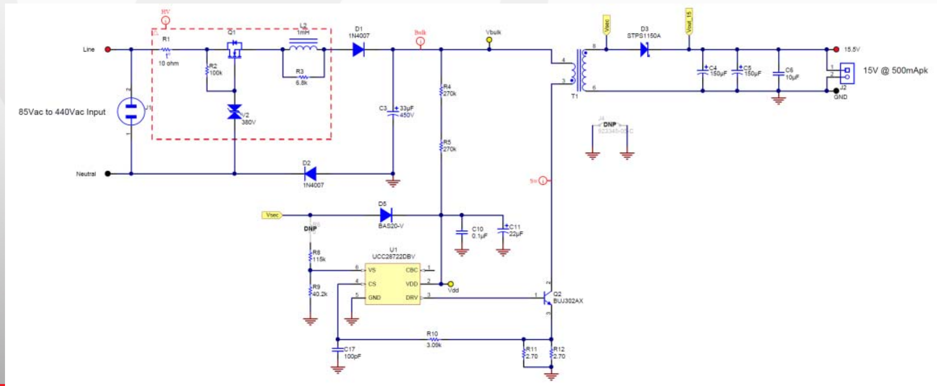


Part	Manufacturer	Voltage Rating		I_C	Est High Vol Cost
		V_{CEO}	V_{CBO}		
STN2580	ST	400V	800V	1A	$0.05
ST13003	ST and others	400V	700V	1.5A	$0.05
STX616-AP	ST	500V	980V	1.5A	$0.09
KSC5026	ON/Fairchild	800V	1,100V	1.5A	$0.10
KSC5027	ON/Fairchild	800V	1,100V	3A	$0.11-$0.12
FJI5603	ON/Fairchild	800V	1,600V	3A	$0.15

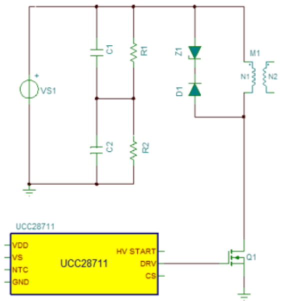
High voltage power switch – BJT switch controllers options

- UCC28720 & UCC28722 designed for high voltage BJTs
  - Current source output rather than voltage source
  - Proportional drive, improves light load performance
  - Ideal for low power, high voltage applications
- High BJT blocking voltage may allow removal of snubber
  - E.g. TIDA-00628 BUJ302AX 1,050-V V_{CESM}

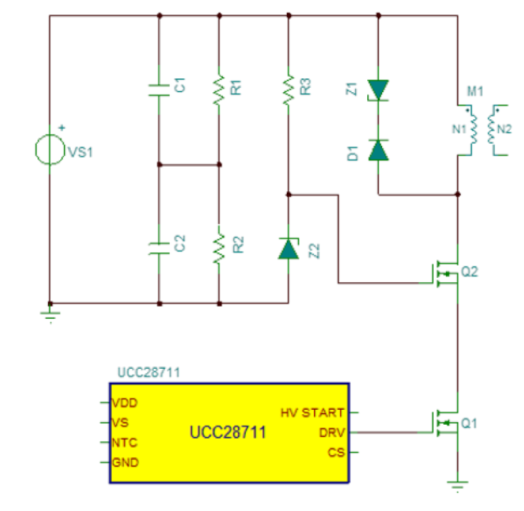




High voltage power switch – cascode arrangement

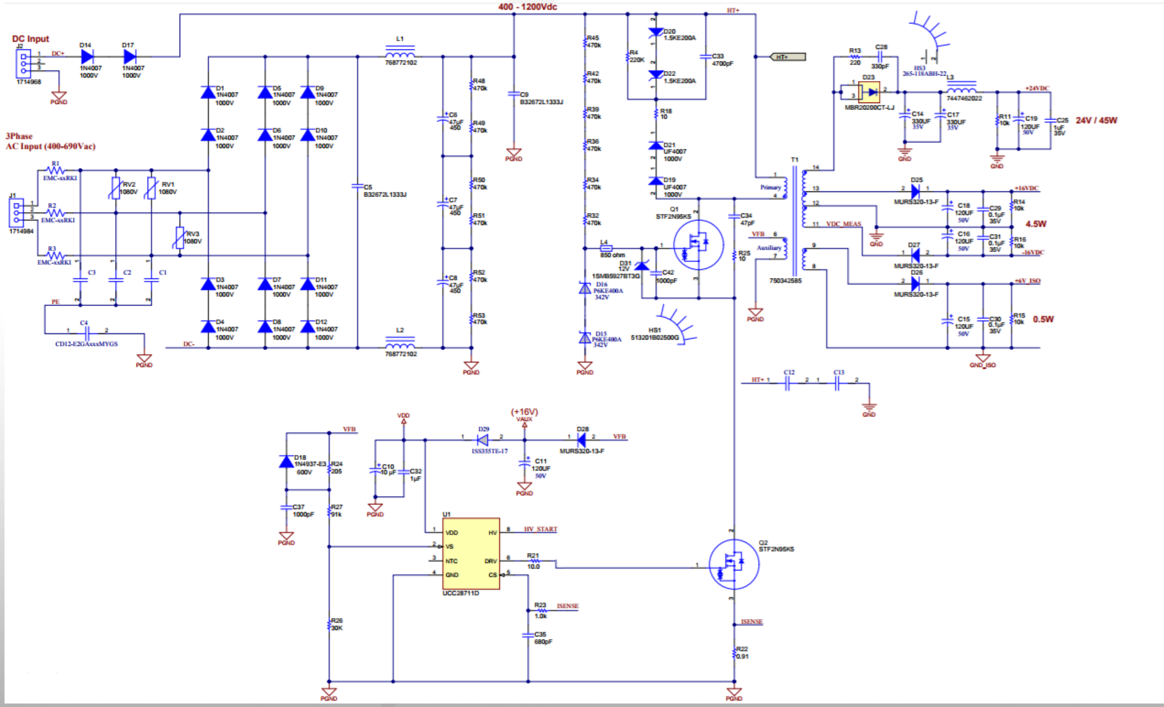


- Cascode two lower voltage devices in series
  - Achieves desired rating with LV devices
- Lower device driven by controller
- Upper device switched via the source/emitter
- For low power, integrated devices can be used as lower cascode switch, e.g UCC28910/28911
  - Reduces the solution cost
- For higher power level, two external switches may be required.



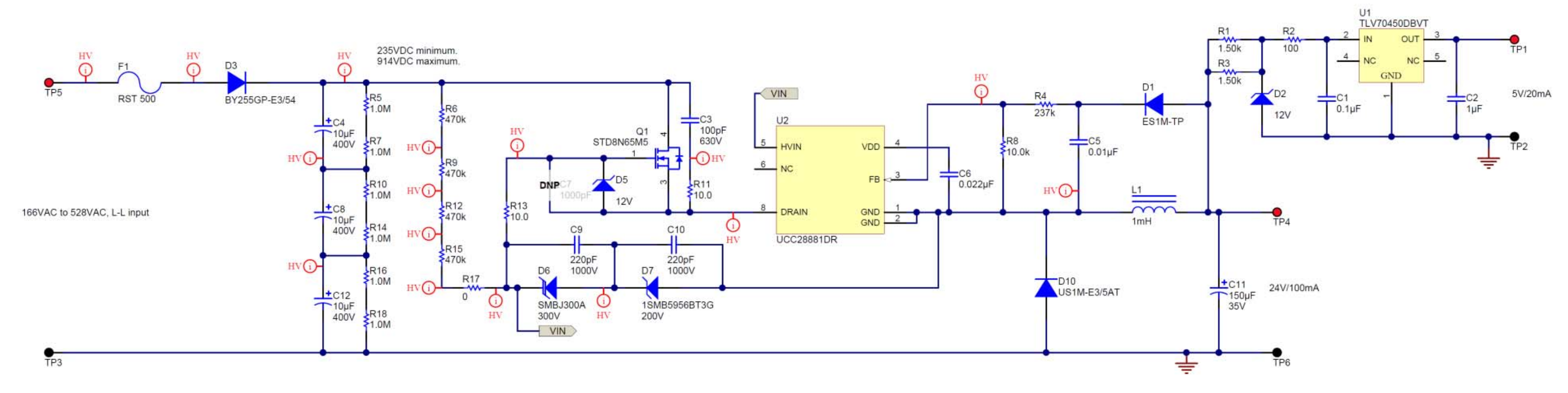
High voltage power switch – cascode example

- E.g. TIDA-00173 50-W Flyback
- 690 V ac, up to 1200 V dc
- ~300 V reflected
- Require Vds 1200 + 300 + spikes + margin = ~1.8-2 kV
- Cascode of two 950-V MOSFETs
- Efficiency > 88% @ full load, 400 V dc



High voltage power switch – non-isolated cascode example

- PMP11302 – same cascode concept used for non-isolated 2.5-W buck design
- UCC28881 (700-V max) cascoded with external MOSFET (650-V max)
- Increase voltage rating to ~1200 V (note three 400-V bulk caps in series)



Conclusions & key take-aways

- High voltage input adds considerable cost and component count to bias supplies
- Various methods to deal with voltage ratings for bulk capacitors and power switch
- Choosing the best configuration for your application bias supply can minimise cost & size overhead, whilst preserving required robustness.
- TI Designs has many high voltage reference designs
  - May be suitable for your application, or give a starting point for your design.