Methods of Designing PWM Flyback Converter

Methods of Designing PWM Flyback Converter: AGENDA

1. Design Procedures for AC/DC Converter
2. Power Supply Specifications (design example)
3. Selection for a Power Supply IC
4. Isolated Flyback Converter Design Example
   ① Basics for Switching AC/DC Conversion
   ② Flyback Converter Operation
   ③ Transformer Design (Numeric Value Calculation)
   ④ Selection for Peripheral Parts
   ⑤ EMI Measures
   ⑥ Output Noise Measrues
   ⑦ PCB Layout Example
5. Transformer Design (Structure Design)

1. Design Procedures for AC/DC Converter

① Determination of Power Supply Specs

② Selection for a Power Supply IC

③ Design & Selection for Peripheral Parts

④ Evaluation and Prototyping

⑤ Production Model Design, Evaluation & Outgoing Inspection

1. Design Procedures for AC/DC Converter

① Determination of Power Supply Specs

1) Input/Output: Vin range, Vout & Vout accuracy
2) Load: Iout, Transient conditions (e.g. sleep to wake-up)
3) Temperature: Max/Min, Cooling
4) Size: Foot print, Height (form factor)
5) Protections: Under voltage, Over voltage, Over heat
6) Environment/Application conditions: Automotive, Space, Communication, RF
7) Cost

② Selection for a Power Supply IC

1) Transformer system or Switching
2) Buck (step-down), Boost (step-up), Buck-Boost, Inverting
3) Linear, Flyback, Forward, etc.
4) Isolated or Non-isolated

1. Design Procedures for AC/DC Converter

③ Design & Selection for Peripheral Parts

1) Conversion parts for mains: Transformer, Diode bridge (rectifier), Diode, Capacitor
2) Peripheral parts for power supply IC
3) Value calculation for parts & optimization
4) Transformer design

④ Evaluation and Prototyping

1) Use of evaluation board & tool provided by IC manufacturer
2) Prototyping, operation and characteristics evaluation
3) Debugging, optimization
4) Determination of conformance and consideration of trade-off

⑤ Production Model Design, Evaluation & Outgoing Inspection

2. Power Supply Specifications

Power Supply Specifications (design example)

① Vin: 85～264VAC

② Vout: 12VDC±5% / 3A 36W

③ Output Ripple Voltage: 200mVp-p

④ Isolation: 3kVAC (primary to secondary)

⑤ Operating Temperature Range: 0 to 50℃

⑥ Efficiency: > 80%

⑦ No Load Input Power: < 0.1W

3. Selection for a Power Supply IC

Power Supply Specs	Points of IC Selection
①Vin: 85～264VAC	⇒Wide input conversion system
②Vou: 12VDC±5% / 3A 36W	⇒External power transistor
③Output Ripple: 200mVp-p	⇒Current mode system
④Isolation: 3kVAC	⇒Feedback control via opt-coupler
⑤Operating Temp Range: 0 to 50℃	⇒Temp grade: -40～85℃
⑥Efficiency: > 80%	⇒Switching system
⑦No Load Input Power: < 0.1W	⇒Internal startup circuit, low power type

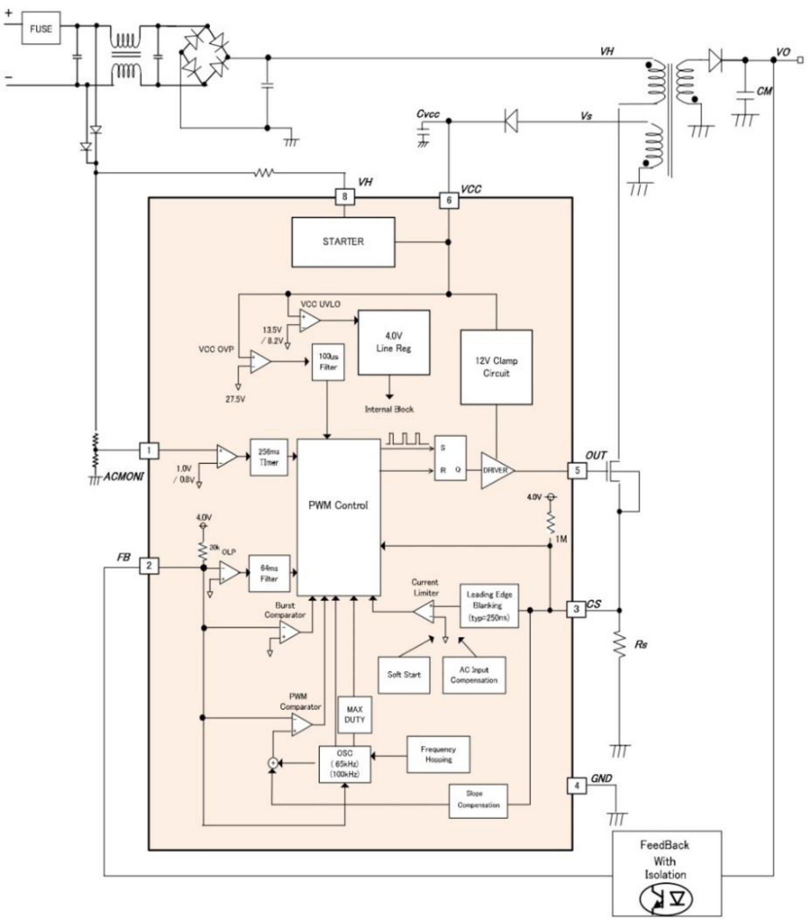
3. Selection for a Power Supply IC

BM1P061FJ : PWM Controller IC for AC/DC Converter

Descriptions:

- PWM switching controller with an internal 650V start-up circuit
- Higher flexibility in design with an external switching MOSFET and a current sense resistor
- Internal start-up circuit and frequency reduction control at a light load for low power consumption and high efficiency
- Available for both isolated and non-isolated converter
- Variation as the BM1Pxxx series

Part #	Package	PWM	VCC OVP
BM1P061FJ	SOP-J8	65kHz	Auto retry
BM1P062FJ			Latched
BM1P101FJ		100kHz	Auto retry
BM1P102FJ			Latched



3. Selection for a Power Supply IC

BM1P061FJ : PWM Controller IC for AC/DC Converter

Features:

- PWM frequency: 65kHz
- Current mode
- Burst operation & frequency reduction control at light load
- Internal 650V start-up circuit
- VCC pin low voltage and over voltage protections
- CS pin open protection
- CS pin Leading-Edge-Blanking
- Over current limiting cycle by cycle
- Current protection with AC voltage compensation
- Soft start
- Over current protection for the
- secondary side
- Frequency hopping

Basic Specs:

・**Operating Supply Voltage Range**	VCC : 8.9V～26.0V VH : < 600V
・**Operating Current**	Normal: 0.60mA (Typ.) Burst: 0.35mA(Typ.)
・**Operating Temp.**	-40℃ ～ +85℃

Package Type:

- SOP-J8 4.90mm×3.90mm ×1.65mm

Applications:

- Wall adopter, TV, Home appliances (cleaner, humidifier, air cleaner, air conditioner, refrigerator, IH cooker, rice cooker & etc)

4. Isolated Flyback Converter Design Example

① Basics for Switching AC/DC Conversion

② Flyback Converter Operation

③ Transformer Design (Numeric Value Calculation)

④ Selection for Peripheral Parts

⑤ EMI Countermeasures

⑥ Output Noise Countermeasures

⑦ PCB Layout Example

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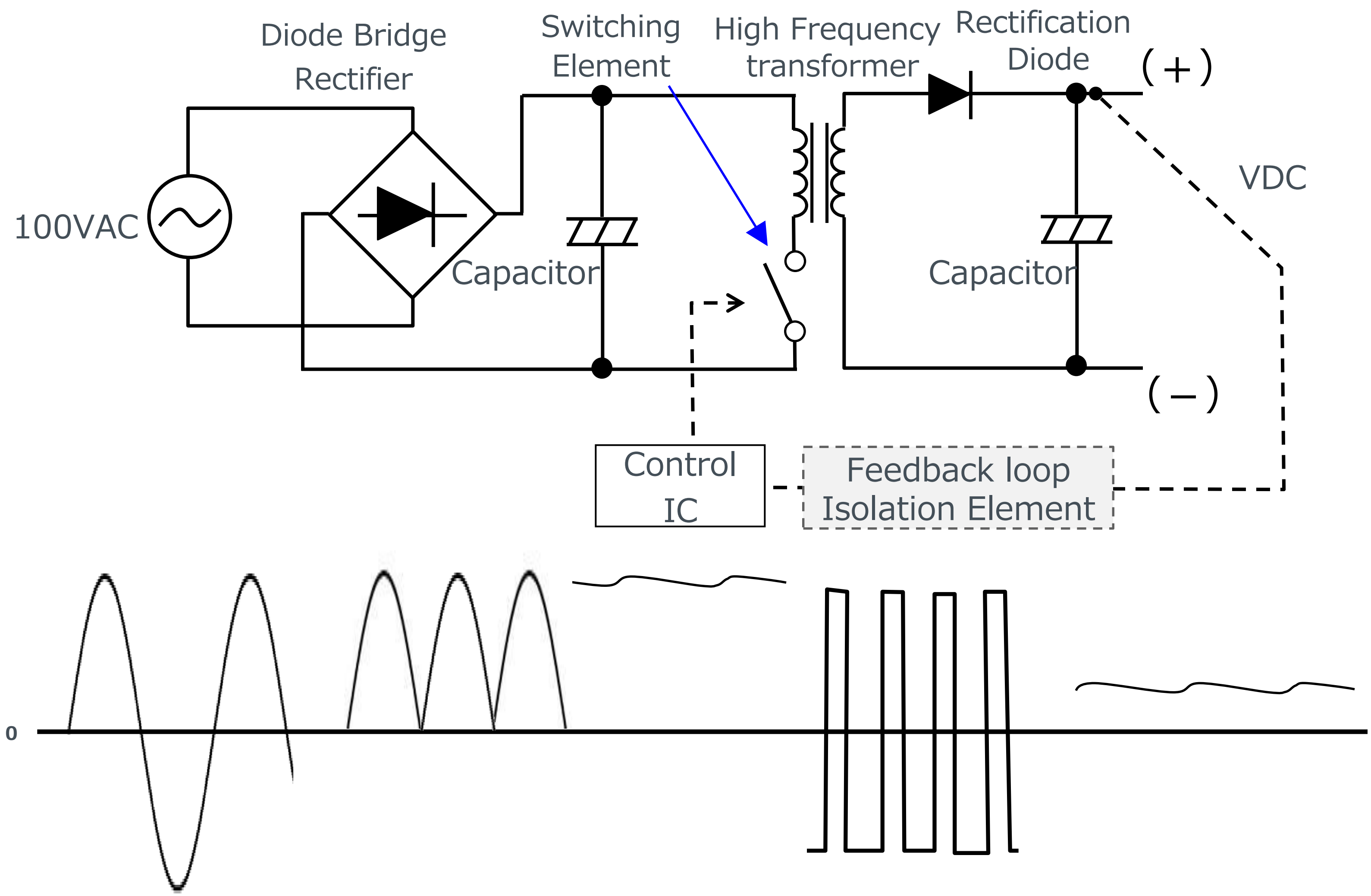
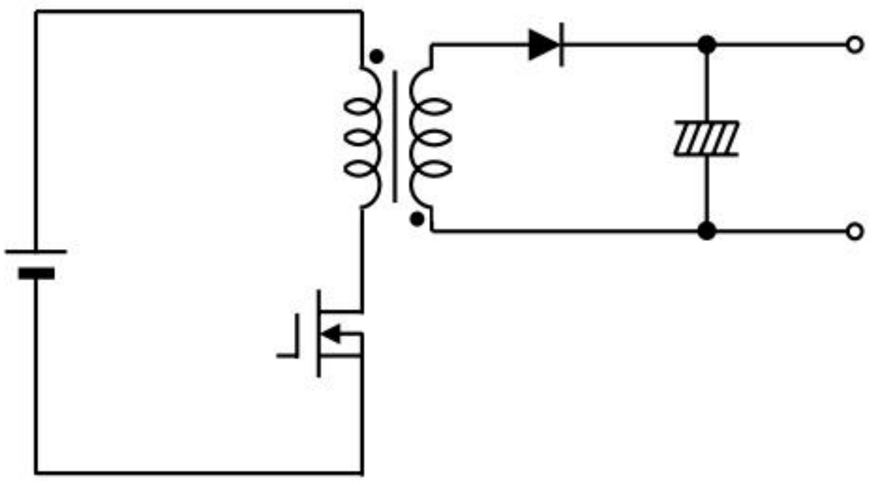
①Basics for Switching AC/DC Conversion



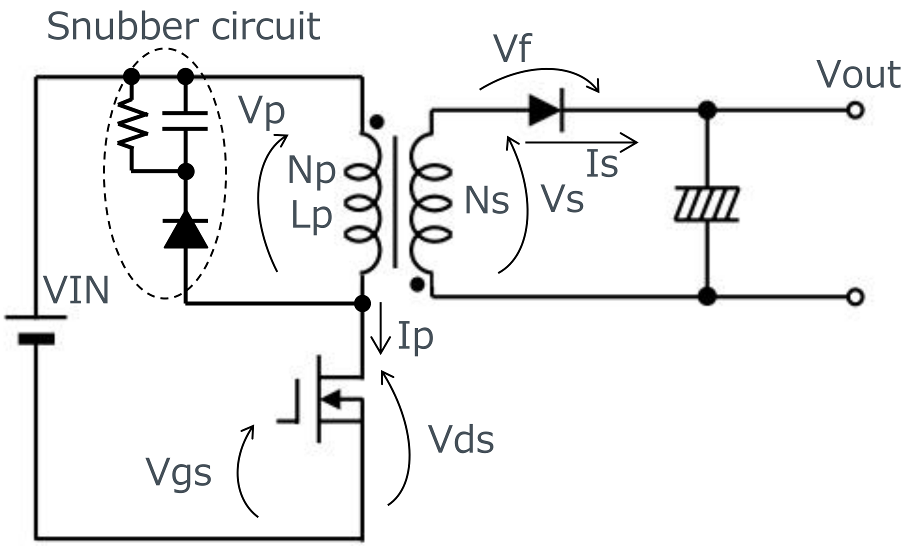
4. Isolated Flyback Converter Design Example

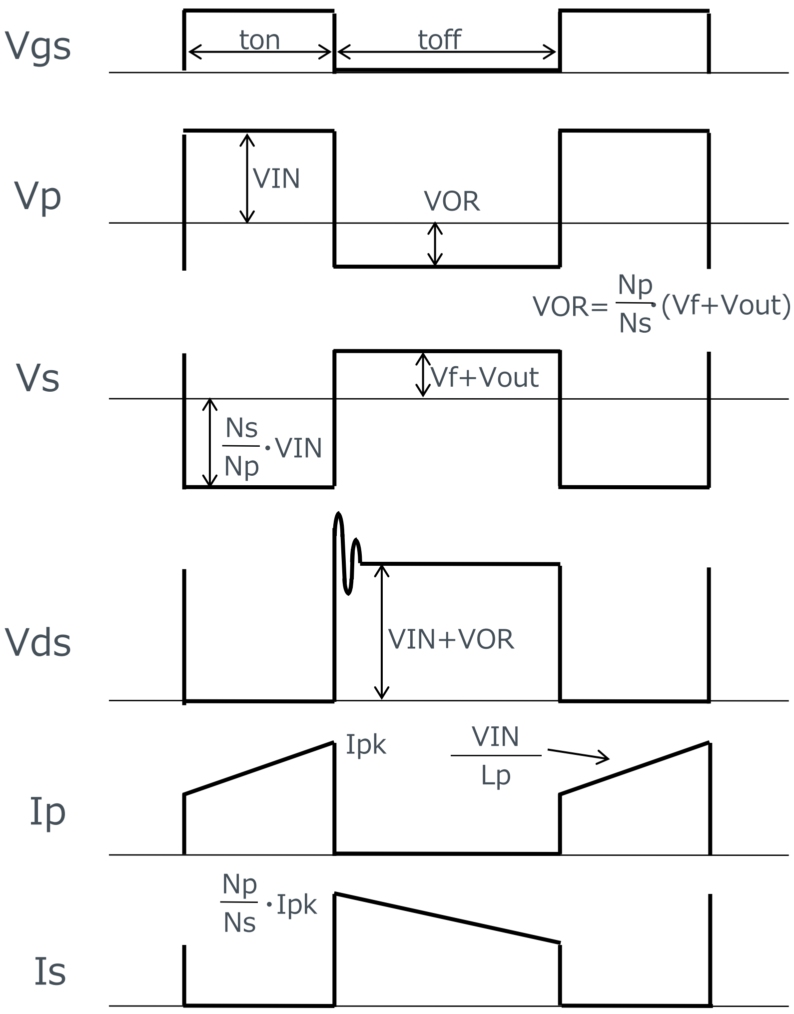
② Flyback Converter Operation



- Configurable into buck or boost converters
- Configurable into isolated or non-isolated converters
- Unsuitable for large output power converters
- Suitable for small switching power supplies
- Wider input voltage range
- Requires a larger capacitance capacitor than the forward converter
- Simple and minimum BOM are required
- Available as an unregulated power supply, setting the output voltage by the winding ratio of transformer, when accurate output voltage is not required

② Flyback Converter Operation: Continuous Mode





- When the MOSFET turns on, a current flows to the primary winding on the transformer, producing a build-up of energy. In this case, the diode remains off.
- When the MOSFET turns off, the stored energy is output from the secondary winding in the transformer through the diode.

4. Isolated Flyback Converter Design Example

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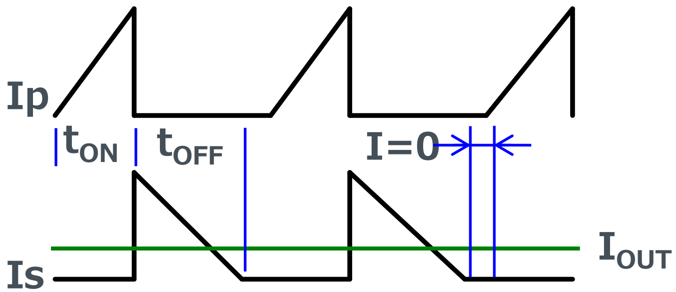
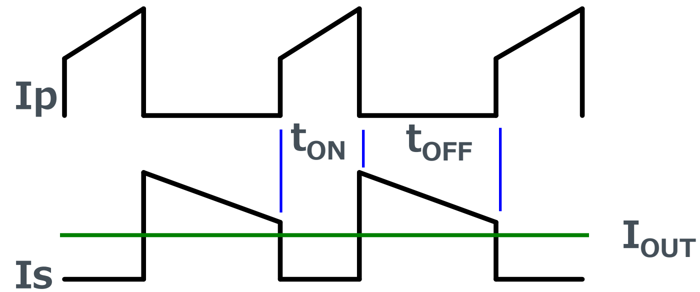
② Flyback Converter Operation: Continuous Mode vs Discontinuous Mode

Item	Discontinuous Mode	Continuous Mode
Operation	 Zero current period exists between the off and on, then a current flows discontinuously.	 A current flows continuously and turns on and off as same as f_{SW}
Transformer	Inductance: down, Size: down, Cost: down	Inductance: up, Size: up, Cost: up
Rectifier Diode	FRD, Cost: down	Faster FRD, Cost: up
Switching Transistor	Power: up, Size: up, Cost: up	Power: down, Size: down, Cost: downup
Output Capacitor	Ripple current: up, Size: up	Ripple current: down, Size: down
Efficiency	Switching loss: down, Efficiency: up	Switching loss: up, Efficiency: down

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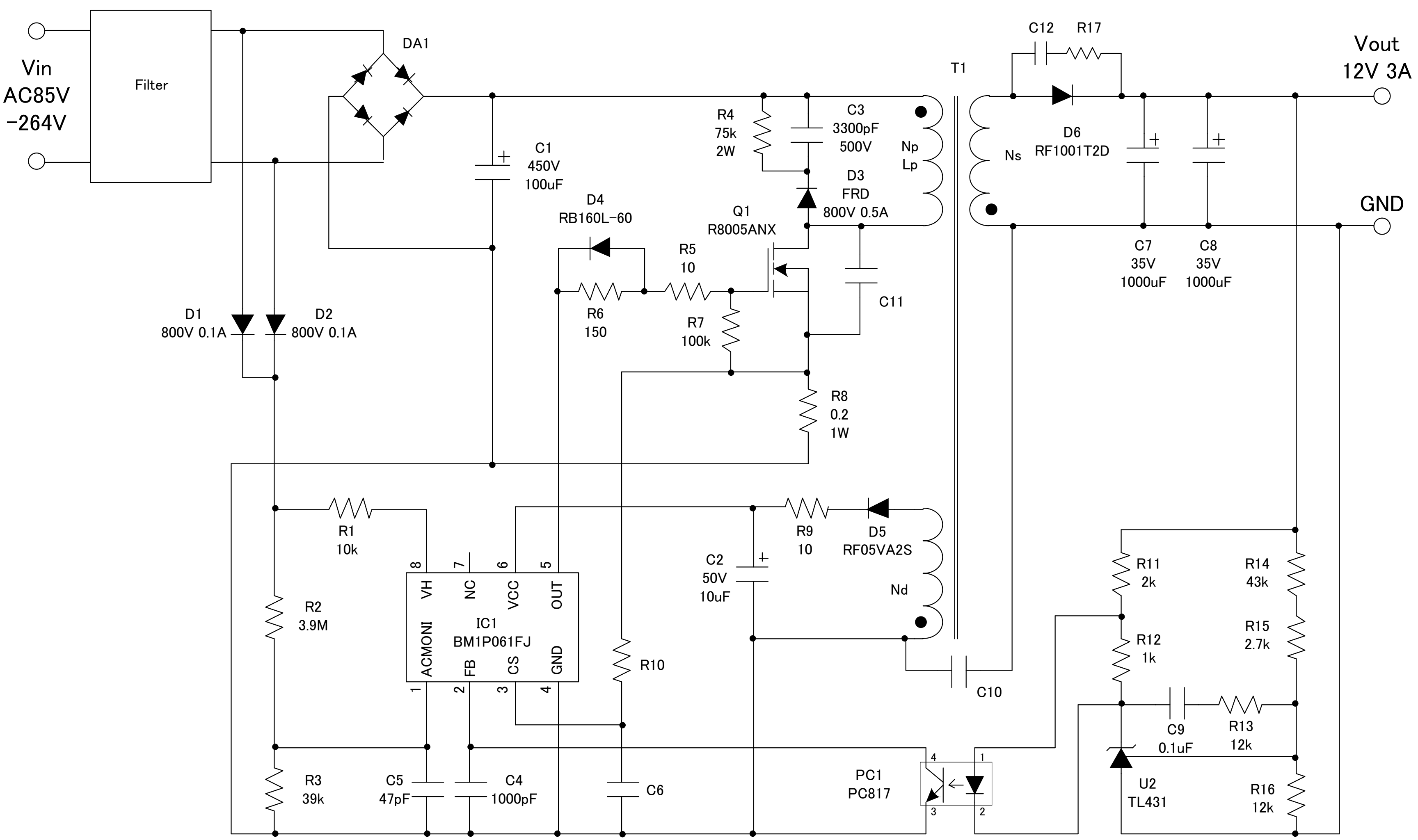
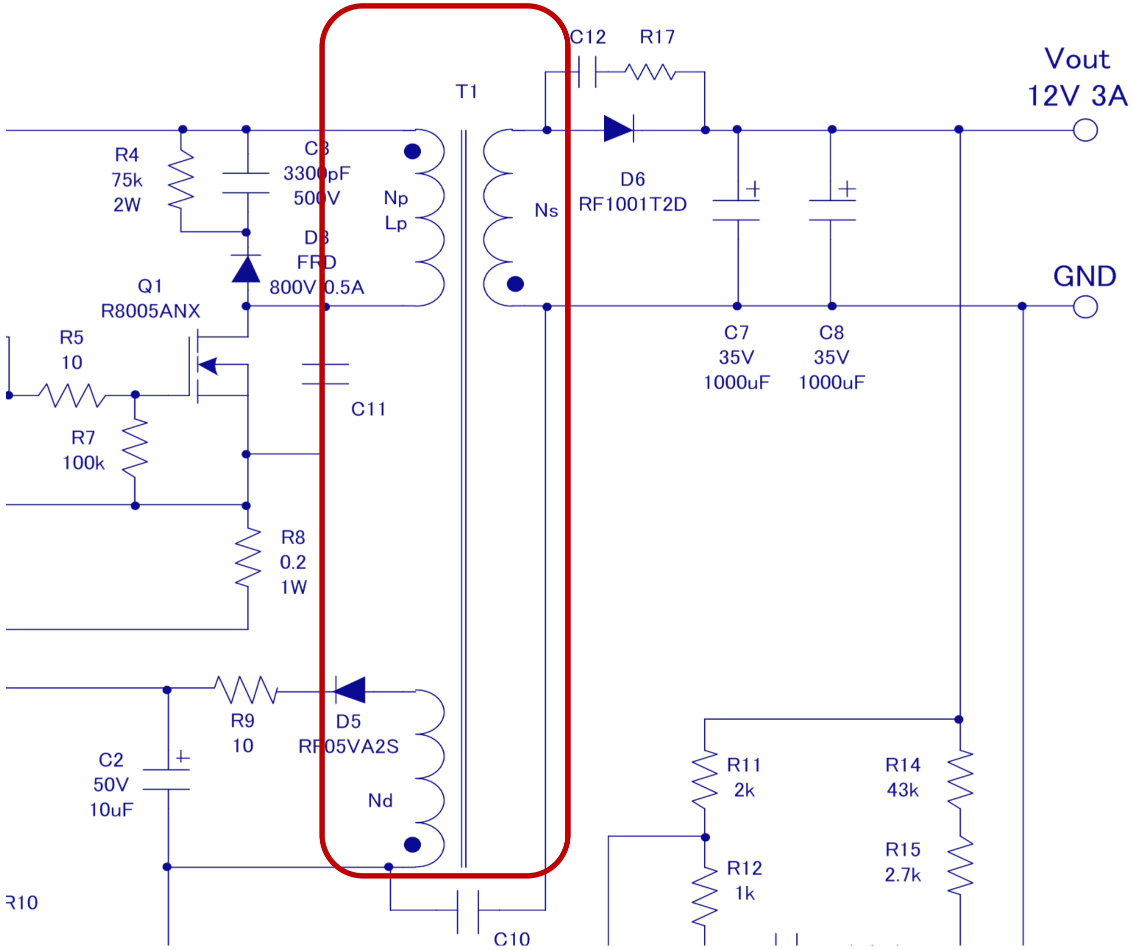
Circut Example: Isolated Flyback AC/DC Converter

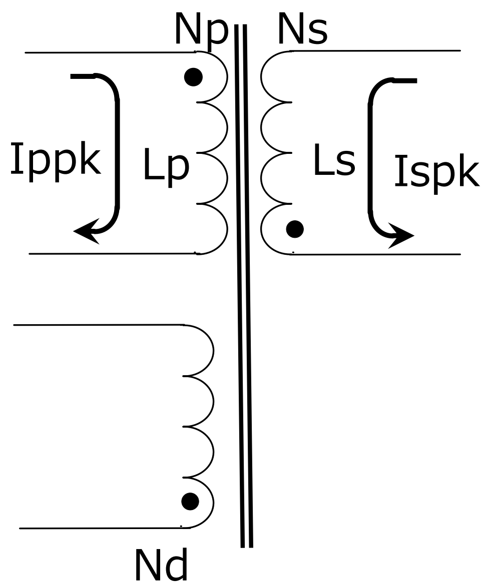


③ Transformer Design (Numeric Value Calculation): Design Procedure for T1



③ Transformer Design (Numeric Value Calculation): Design Procedure for T1

1. Setting the fyback voltage: VOR
2. Calculation for the inductance of secondary winding: Ls, and the secondary side peak current: Ispk
3. Calculation for the inductance of primary winding: Lp, and the secondary side peak current: Ippk
4. Fixing the core size of transformer
5. Calculation for turns of the primary winding: Np
6. Calculation for turns of the secondary winding: Ns
7. Calculation for turns of the VCC winding: Nd



Derive these values as parameters of transformer

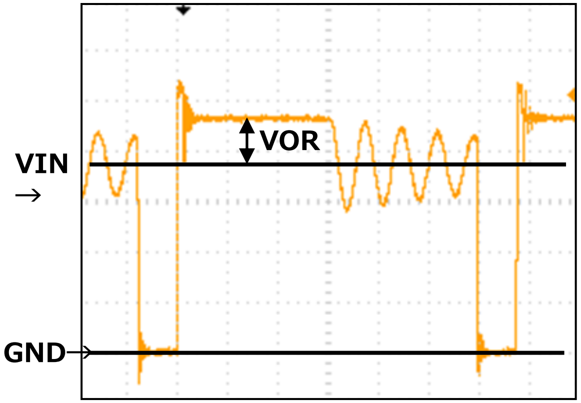
Core	Size
Lp	Inductance
Np	Turns
Ns	Turns
Nd	Turns

③ Transformer Design (Numeric Value Calculation):

1. Setting the fyback voltage: **VOR**

- VOR is the product of VO(Vout+Vf) by Np:Ns (winding ratio)

- When VOR is determined, Np:Ns and duty cycle are fixed



MOSFET Vds

$$VOR = VO \times \frac{Np}{Ns} = \frac{ton}{toff} \times VIN$$

$$\Rightarrow \frac{Np}{Ns} = \frac{VOR}{VO}$$

$$\Rightarrow Duty = \frac{VOR}{VIN + VOR}$$

Ex. When VIN = 95V(AC85V x 1.4 x 0.8), VOR = 65V and Vf = 1V :

$$\frac{Np}{Ns} = \frac{VOR}{VO} = \frac{VOR}{Vout + Vf} = \frac{65V}{12V + 1V} = 5$$

$$Duty(max) = \frac{VOR}{VIN(min) + VOR} = \frac{65V}{95V + 65V} = 0.406$$

* VOR should be adjusted to < 0.5, when the duty cycle becomes > 0.5.

4. Isolated Flyback Converter Design Example

③ Transformer Design (Numeric Value Calculation):

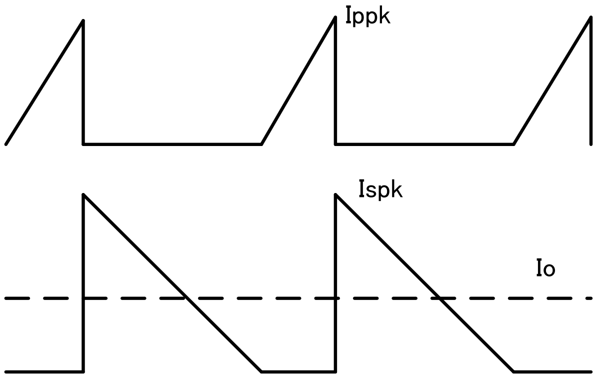
2. Calculation for the inductance of secondary winding: **Ls**, and the secondary side peak current: **Ispk**

- When Iomax = Io x 1.2 =3.6A with a safe margin:

$$Ls < \frac{(Vout + Vf) \times (1 - Duty)^2}{2 \times Iomax \times fswmax}$$

$$= \frac{(12V + 1V) \times (1 - 0.406)^2}{2 \times 3.6A \times 70kHz} = 9.1uH$$

$$Ispk = \frac{2 \times Iomax}{1 - Duty(max)} = \frac{2 \times 3.6A}{1 - 0.406} = 12.1A$$



Current wave forms for Ippk and Ispk

3. Calculation for the inductance of primary winding: **Lp**, and the secondary side peak current: **Ippk**

$$Lp = Ls \times \left(\frac{Np}{Ns}\right)^2 = 9.1uH \times 5^2 = 228uH$$

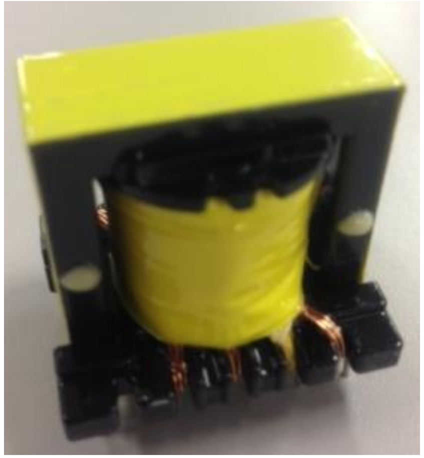
$$Ippk = Ispk \times \frac{Ns}{Np} = 12.1A \times \frac{1}{5} = 2.42A$$

4. Isolated Flyback Converter Design Example

③ Transformer Design (Numeric Value Calculation):

4. Fixing the **core size** of transformer

- Based on Po=36W, the core size of transformer is fixed to the EER28



Transformer with the EER28 size core

Transformer Core for Output Power

Output Power: Po(W)	Core size	Core x-section: Ae(mm^2)
to 30	EI25/EE25	41
to 60	EI28/EE28/EER28	84

4. Isolated Flyback Converter Design Example

③ Transformer Design (Numeric Value Calculation):

5. Calculation for turns of the primary winding: **Np**

$$Np > \frac{VIN \times ton}{Ae \times Bsat} = \frac{Lp \times Ippk}{Ae \times Bsat}$$

- Maximum flux density: B(T) of a typical ferrite core is 0.4T at 100℃, then Bsat is considered as 0.35T

$$Np > \frac{Lp \times Ippk}{Ae \times Bsat} = \frac{228uH \times 2.42A}{84mm^2 \times 0.35T} = 18.8\ turns$$

⇒ Np is considered as > 19 turns

- To avoid magnetic saturation, Np is determined from the AL-Value vs NI characteristics

When AL-Value=200nH/turns^2:

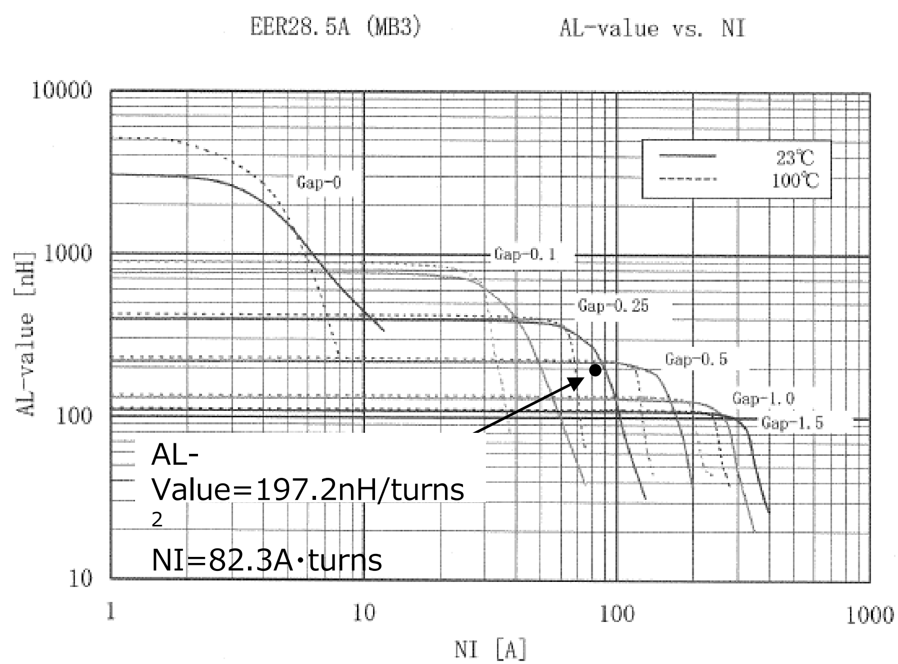
$$Np = \sqrt{\frac{Lp}{AL\text{-}Value}} = \sqrt{\frac{228uH}{200nH/turns^2}} = 33.7turns$$

⇒ Np is considered as 34 turns

When AL-Value=228uH/34^2=197.2nH/turns^2

$$NI = Np \times Ippk = 34turns \times 2.42A = 82.3A \cdot turns$$

- Verify it is within the tolerance from the EER28 AL-Value vs NI characteristics. When it is over, modification of Np is required



③ Transformer Design (Numeric Value Calculation):

6. Calculation for turns of the secondary winding: **Ns**

$$\frac{Np}{Ns} = 5 \quad \rightarrow \quad Ns = \frac{34}{5} = 6.8 \ \text{turns}$$

⇒ Ns is considered as 7 turns

7. Calculation for turns of the VCC winding: **Nd**

• When VCC=15V, Vf_vcc=1V:

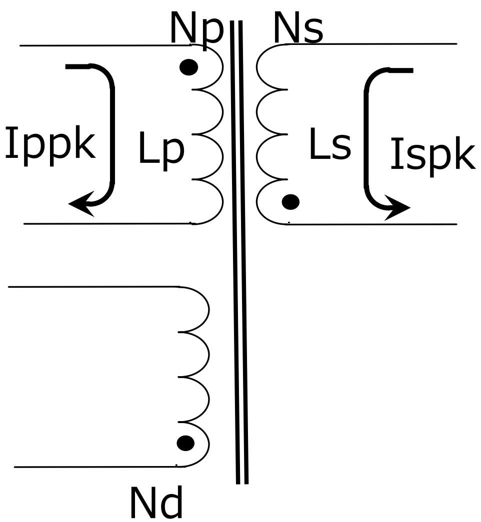
$$Nd = Ns \times \frac{VCC + Vf\_vcc}{Vout + V\ f}$$

$$= 7\text{turns} \times \frac{15V + 1V}{12V + 1V} = 8.6\text{turns}$$

⇒ Nd is considered as 9 turns

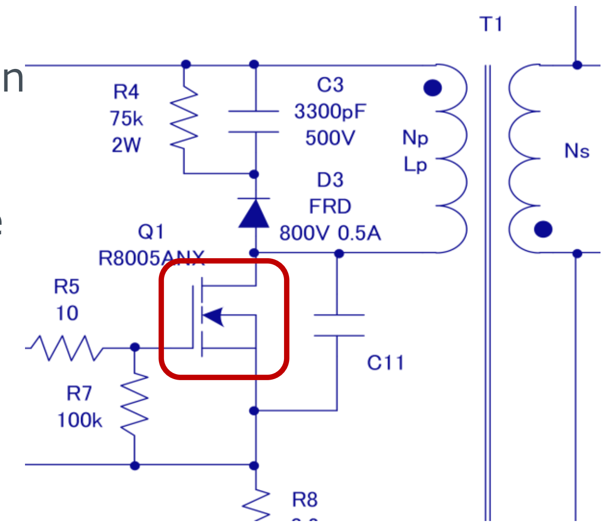
Based on the above calculations, the transformer's specs are:

Core	JFE MB3 EER28.5A or Equal Quality
Lp	228 µH
Np	34 turns
Ns	7 turns
Nd	9 turns



4. Isolated Flyback Converter Design Example

④ Selection for Peripheral Parts: MOSFET Q1



- Considerations to select MOSFET are Vgs max, Peak Ids, Ron loss, and package power dissipation
- Note that self heating by Ron loss becomes high under the worldwide input conditions (85VAC to 264VAC) because the MOSFET's on-time will be long at low input voltage
- Difficult to select with a desktop calculation only

⇒ Need an empirical rule and actual evaluations for the final determination. Countermeasures for thermal radiation, e.g. adding a heat sink, are required as needed

- Determination of Vds: Vds is calculated by the following

$$Vds(max) = Vin(max) + VOR + Vspike$$
$$= 264V \times 1.41 + (12V+1V) \times 34/7 + Vspike = 435V + Vspike$$

* Calculation of Vspike is difficult. In this case, Vds is considered as 800V from an empirical rule with addition of a snubber circuit.

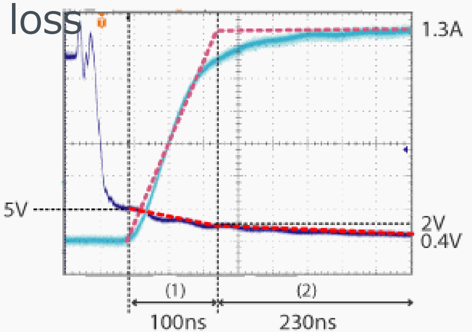
- Ids rating: Select Ippk x 2 as a rough estimate

⇒ Select R8005ANX (800V 5A 1.6Ω TO-220F from ROHM)

4. Isolated Flyback Converter Design Example

④ Selection for Peripheral Parts: MOSFET Q1

Ex. Measurement method for MOSFET power loss



First, put the approximation line along On-time waveform as drwaing on the left as --------

From the integration formula,

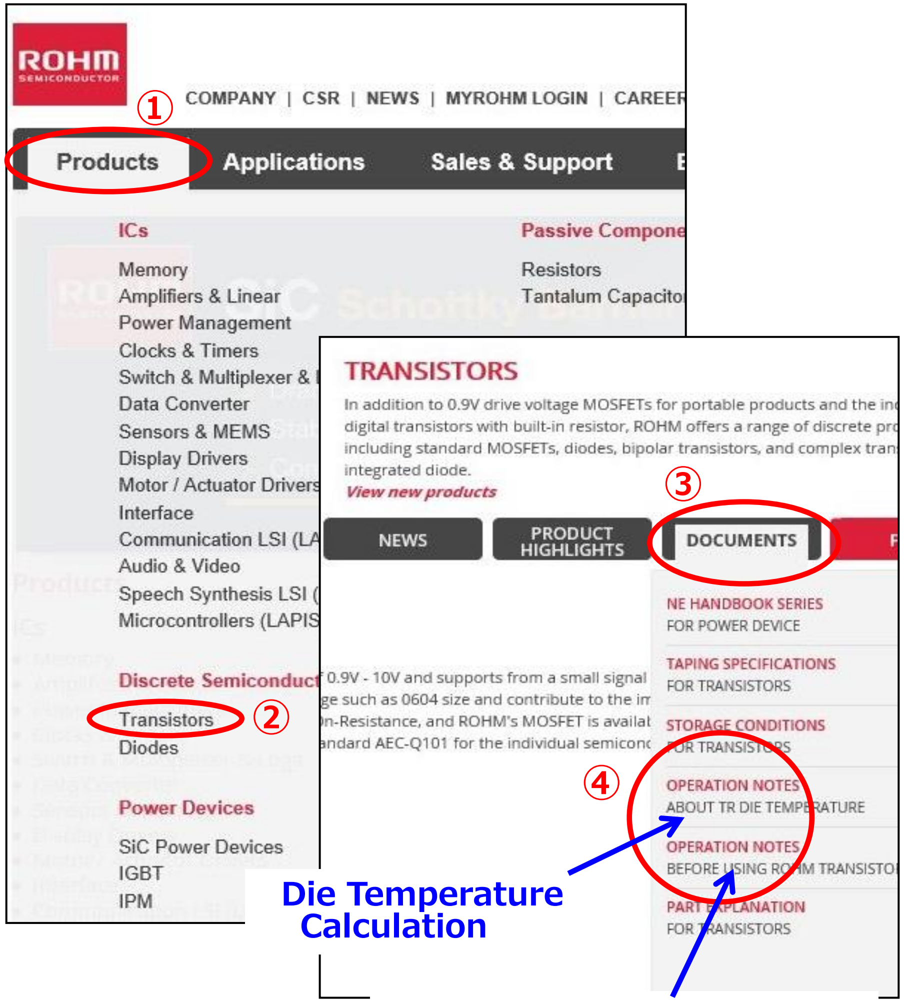
(1) Zone

$$\int IVdt = (1/6)\times 100ns\times (2\cdot 0A\cdot 5V + 0A\cdot 2V + 1.3A\cdot 5V + 2\cdot 1.3A\cdot 2V) = 1.95\times 10^{-7}(J)$$

(2) Zone

$$\int IVdt = (1/6)\times 230ns\times (2\cdot 1.3A\cdot 2V + 1.3A\cdot 0.4V + 1.3A\cdot 2V + 2\cdot 1.3A\cdot 0.4V) = 3.59\times 10^{-7}(J)$$

When OFF → ON Total : $5.54\times 10^{-7}(J)$



Support Site
http://www.rohm.com/web/global/groups/-/group/groupname/Transistors

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④ Selection for Peripheral Parts: Input Capacitor C1

- Calculation for C1 capacitance

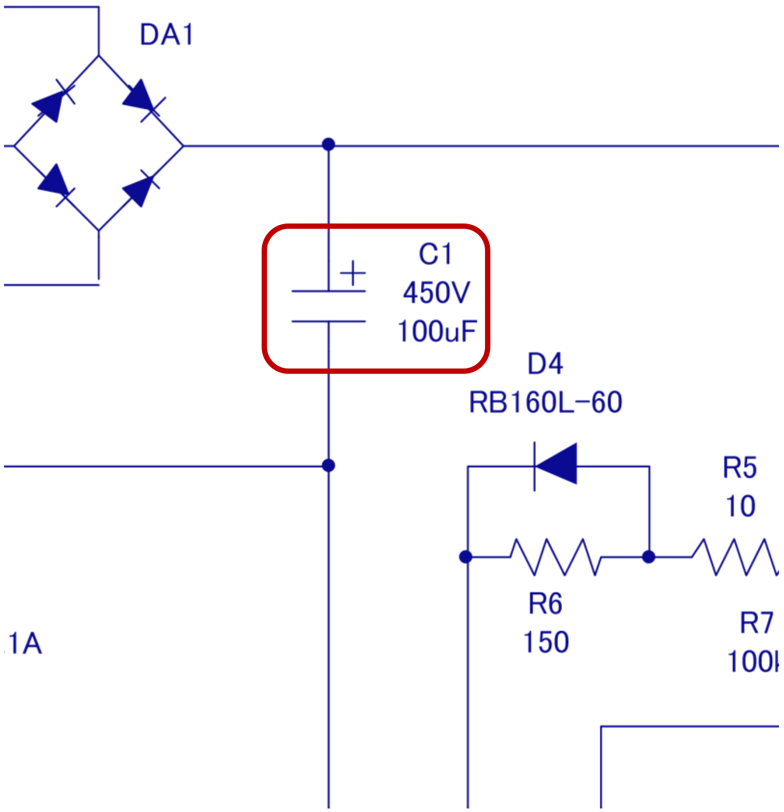
  Pout = 12V x 3A = 36W

  C1 : 36 x 2 = 72 ⇒ Considered as 100μF

Input Capacitor Capacitance (rough estimate)

Input Voltage (VAC)	Cin (μF)
85 to 264	2 X Pout (W)
180 to 264	1 x Pout (W)

* The above conversion factors are a rough estimate for the full-bridge rectification. Further considerations will be needed depending on requirements of power supply, e.g. Vout hold time.



- Withstand voltage is estimated as

  VAC(max) x 1.41

  Ex. When 264VAC:

  264V x 1.41 = 372V ⇒ Considered as 400V

④ Selection for Peripheral Parts: Current Sense Resistor R8

- The current sense resistor is used for output over loading protections and slope compensation of current mode, limiting the primary side current.
- Due to these functions, the primary side inductance or the input voltage may affect the R8 setting.
- The BM1PXXX series includes the over load protection with AC voltage compensation which compensate a fluctuation of over load protection activation threshold by the input voltage level.

$$R8=\frac{Vcs\_limit}{Ippk}=\frac{Vcs+ton\times 20mV/us}{Ippk}=\frac{Vcs+\frac{Duty}{fsw}\times 20mV/us}{Ippk}=\frac{0.4V+\frac{0.406}{65kHz}\times 20mV/us}{2.42A}=0.217\ \Omega$$

⇒ Considered as 0.2Ω

＊ Checking for the over load protection threshold at the actual circuit is necessary.

- Power loss of R8: P_R8

$$P\_R8(peak)=Ippk^2\times R8=2.42^2\times 0.2=1.17W$$

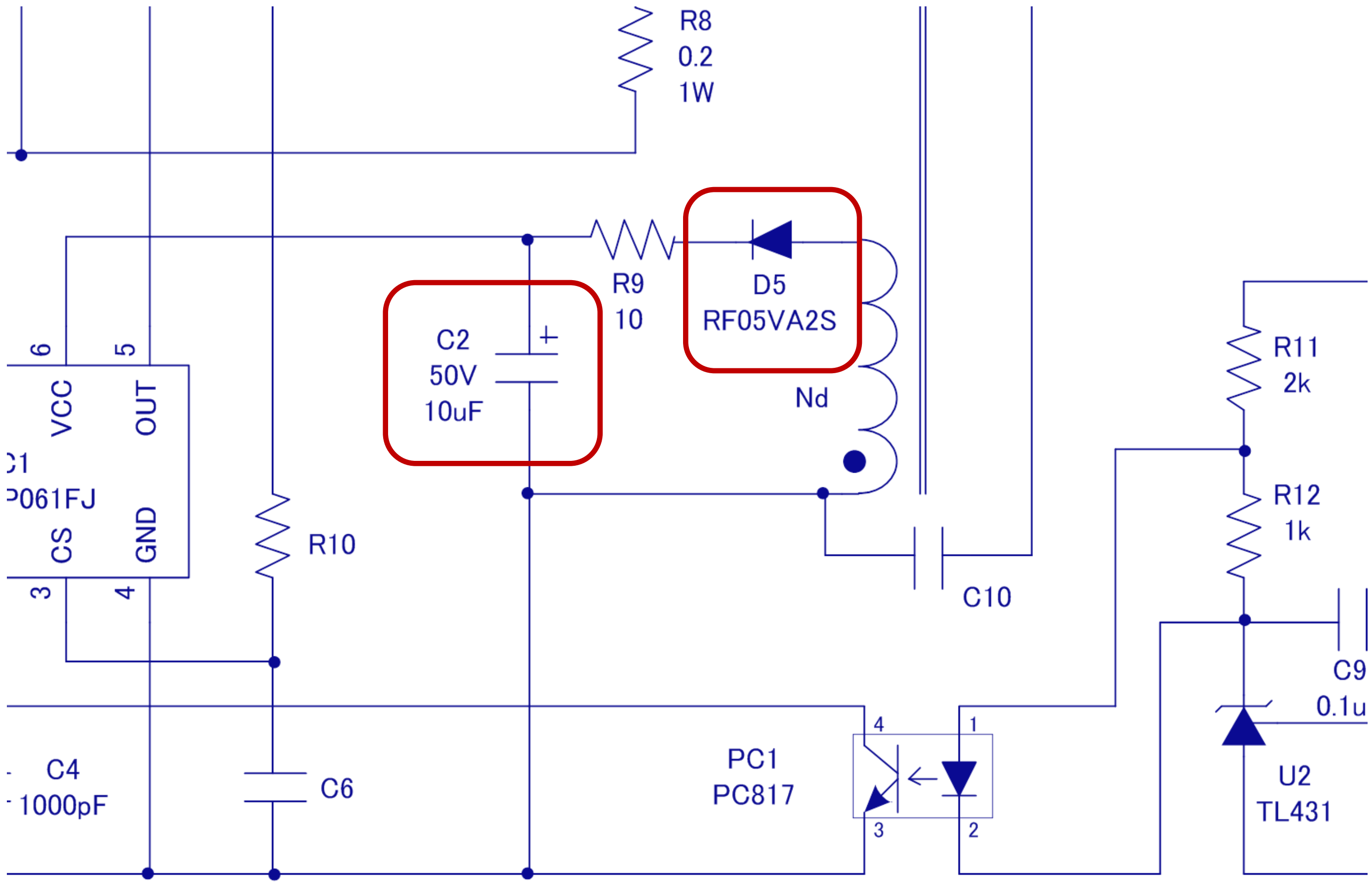
$$P\_R8(rms)=Iprms^2\times R8=\left(Ippk\times\sqrt{\frac{Duty}{3}}\right)^2\times R8=\left(2.42\times\sqrt{\frac{0.406}{3}}\right)^2\times 0.2=0.15W$$

⇒ Considered as > 1W, including a pulse tolerance

＊ As for a pules tolerance, it may depend on the resistor structure even the same power rating. Ask the detail to the resistor manufacturer.

4. Isolated Flyback Converter Design Example

④ Selection for Peripheral Parts: VCC Diode D5 & VCC Capacitor C2



4. Isolated Flyback Converter Design Example

④ Selection for Peripheral Parts: VCC Diode D5

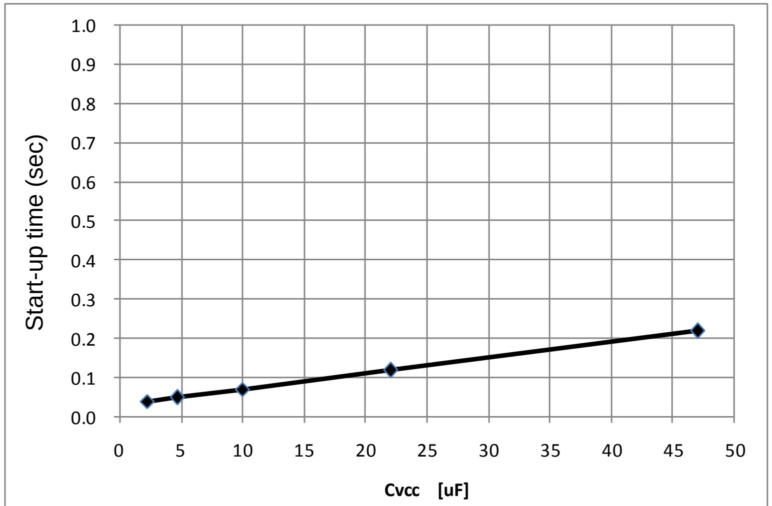
- Recommend a fast recovery diode for the VCC diode
- Reverse voltage to the VCC diode: $\mathrm{Vdr} = \mathrm{VCC(max)} + \mathrm{VINmax} \times \dfrac{\mathrm{Nd}}{\mathrm{Np}}$
- When VCC(max) = 29V : $\mathrm{Vdr} = 29\mathrm{V} + 372\mathrm{V} \times \dfrac{9}{34} = 127\mathrm{V}$
- Considered as 127.4V/0.7=182V with a safe margin

  ⇒ Select 200V diode (ex. RF05VA2S 200V 0.5A from ROHM)

④ Selection for Peripheral Parts: VCC Capacitor C2

- The VCC capacitor C2 is needed to settle the VCC voltage of the IC
- > 2.2μF is required (ex. 50V 10μF)

- C2 also works to determine the start-up time with the VH pin resistor R1
- See the chart for C2 vs start-up time as a reference



Start-up Time (as a reference)

4. Isolated Flyback Converter Design Example

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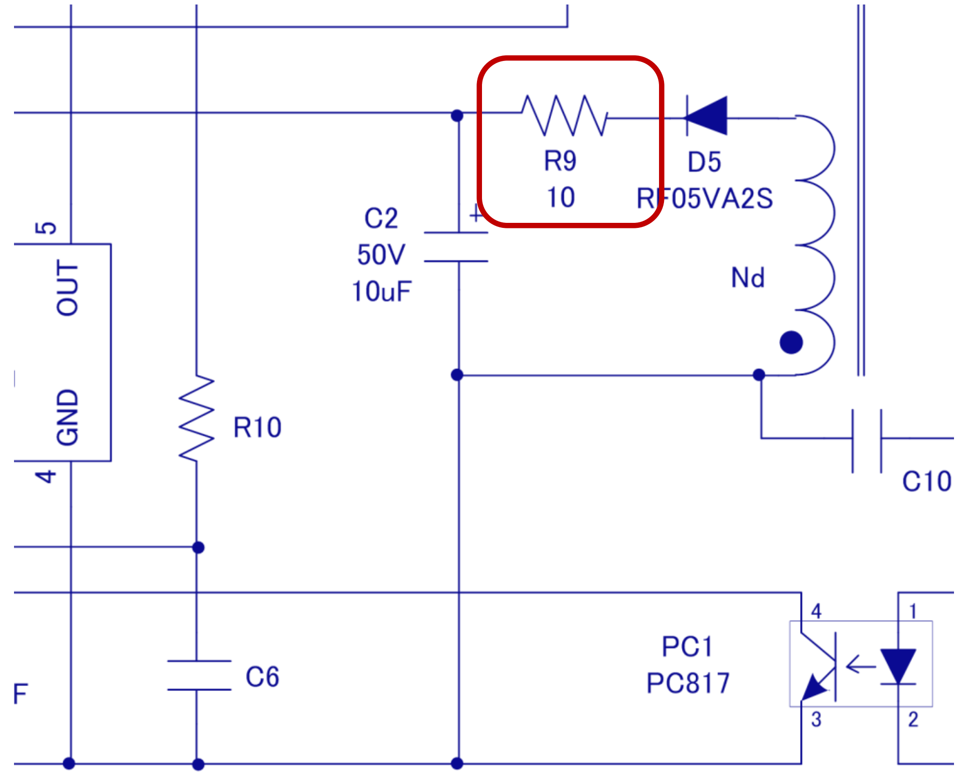
④ Selection for Peripheral Parts: VCC winding Surge Voltage limiting Resistor R9

- Due to a leakage inductance (Lleak) of transformer, a large surge voltage (spike noise) will occur at the instant when the MOSFET turns off

- The surge voltage induce a high voltage in the VCC winding and it will activate the VCC overvoltage protection

- To reduce the surge voltage, insert R2 (5 to 22Ω) as a limiting resistor

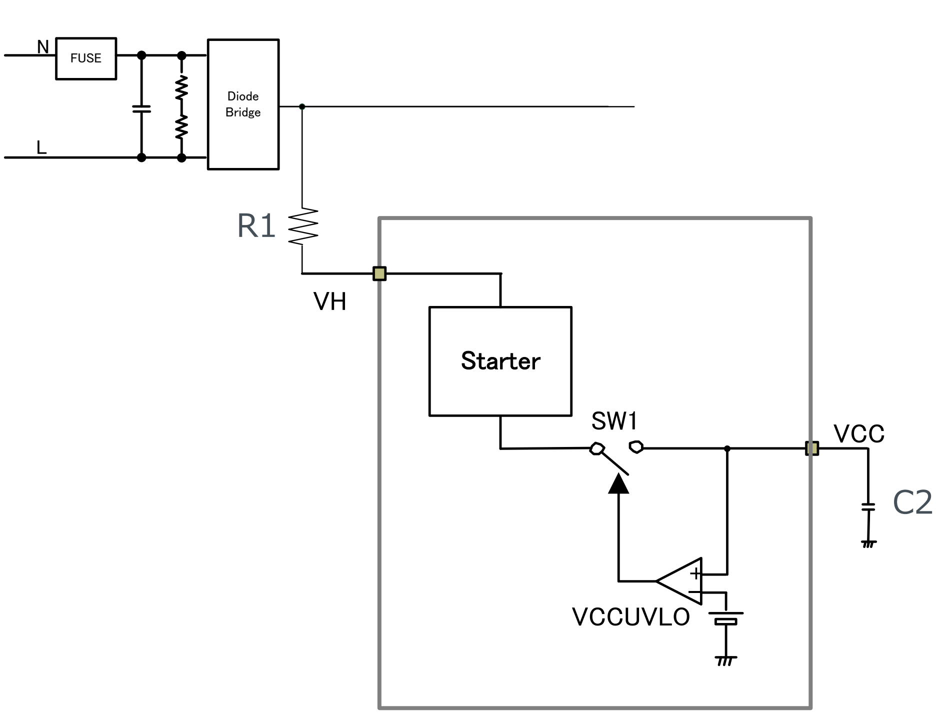
* Need to check the raise of the VCC voltage with the actual circuit

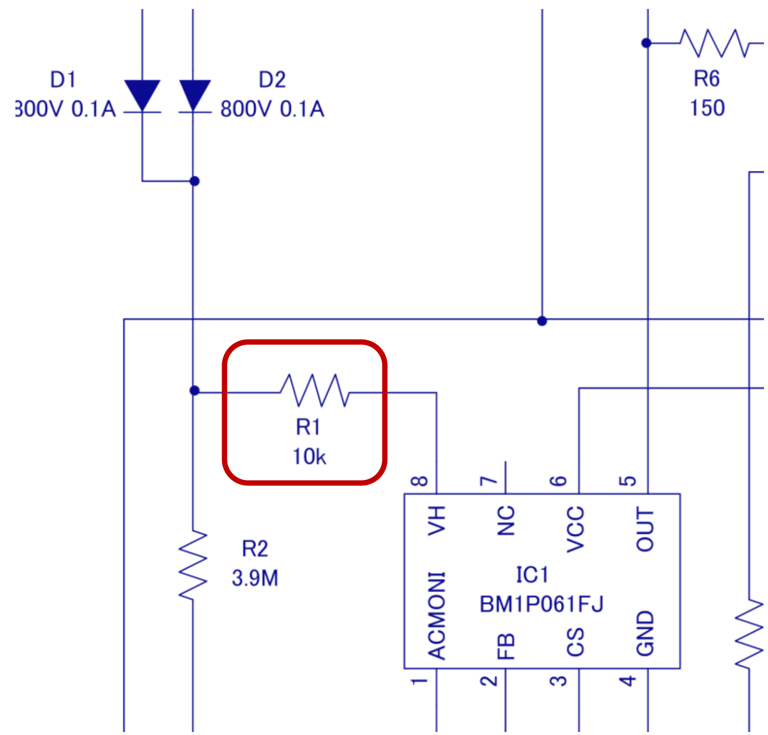


4. Isolated Flyback Converter Design Example

④ Selection for Peripheral Parts: VH pin Resistor R1

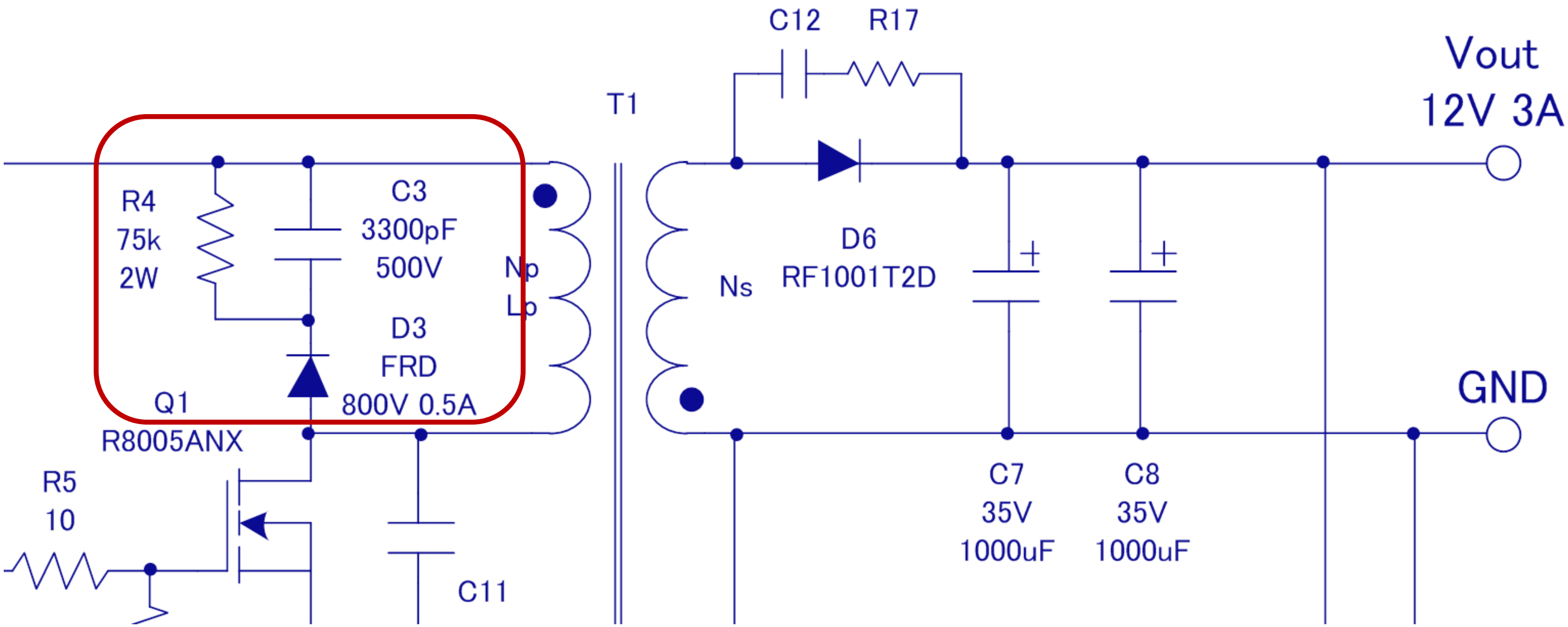
- The start-up time is determined by the current into the VH pin through R1 and the capacitance of VCC capacitor C2
- Since a large current flows to GND from the VH line when the VH pin short-circuits to GND, insert R1 (5k to 60kΩ) between the VH line and the VH pin as a current limiter
- R1 should tolerate the power of VH/R1 when short-circuited





4. Isolated Flyback Converter Design Example

④ Selection for Peripheral Parts: Snubber Circuit C3, D3 & R4



④ Selection for Peripheral Parts: Snubber Circuit C3, D3 & R4

- Due to a leakage inductance (Lleak) of transformer, a large surge voltage (spike noise) will occur at the instant when the MOSFET turns off and it may destroy the MOSFET
- A RCD snubber circuit is required to suppress the surge voltage

1) Determination of the clamp voltage (Vclamp) and the clamp ripple voltage (Vripple)

- Determine Vclamp based on the MOSFET Vds considering with a safe margin:
  Vclamp = 800V x 0.8 = 640V
- Vripple is estimated around 50V

2) R4 Selection

$$R4 < 2 \times Vclamp \times \frac{Vclamp - VOR}{Lleak \times Ip^2 \times fsw(max)}$$

- Lleak = Lp x 10% = 228μH x 10% = 23μH: $R4 < 2 \times 640V \times \frac{640V - 65V}{23uH \times 2.42^2 \times 70kHz} = 78k\Omega$

  ⇒ Considered as R4=75kΩ

- Loss of R4, P_R4 : $P\_R4 = \frac{(Vclamp - VIN)^2}{R4} = \frac{(640 - 372)^2}{75k\Omega} = 0.96W$

  ⇒ Considered as 2W with a safe margin

4. Isolated Flyback Converter Design Example

④ Selection for Peripheral Parts: Snubber Circuit C3, D3 & R4

3) C3 Selection

$$C3 > \frac{Vclamp}{Vripple \times fsw(min) \times R4} = \frac{640V}{50V \times 60kHz \times 75k\Omega} = 2844pF$$

⇒ Considered as 3300pF

- Voltage for C3: 640V - 264 x 1.41 = 268V

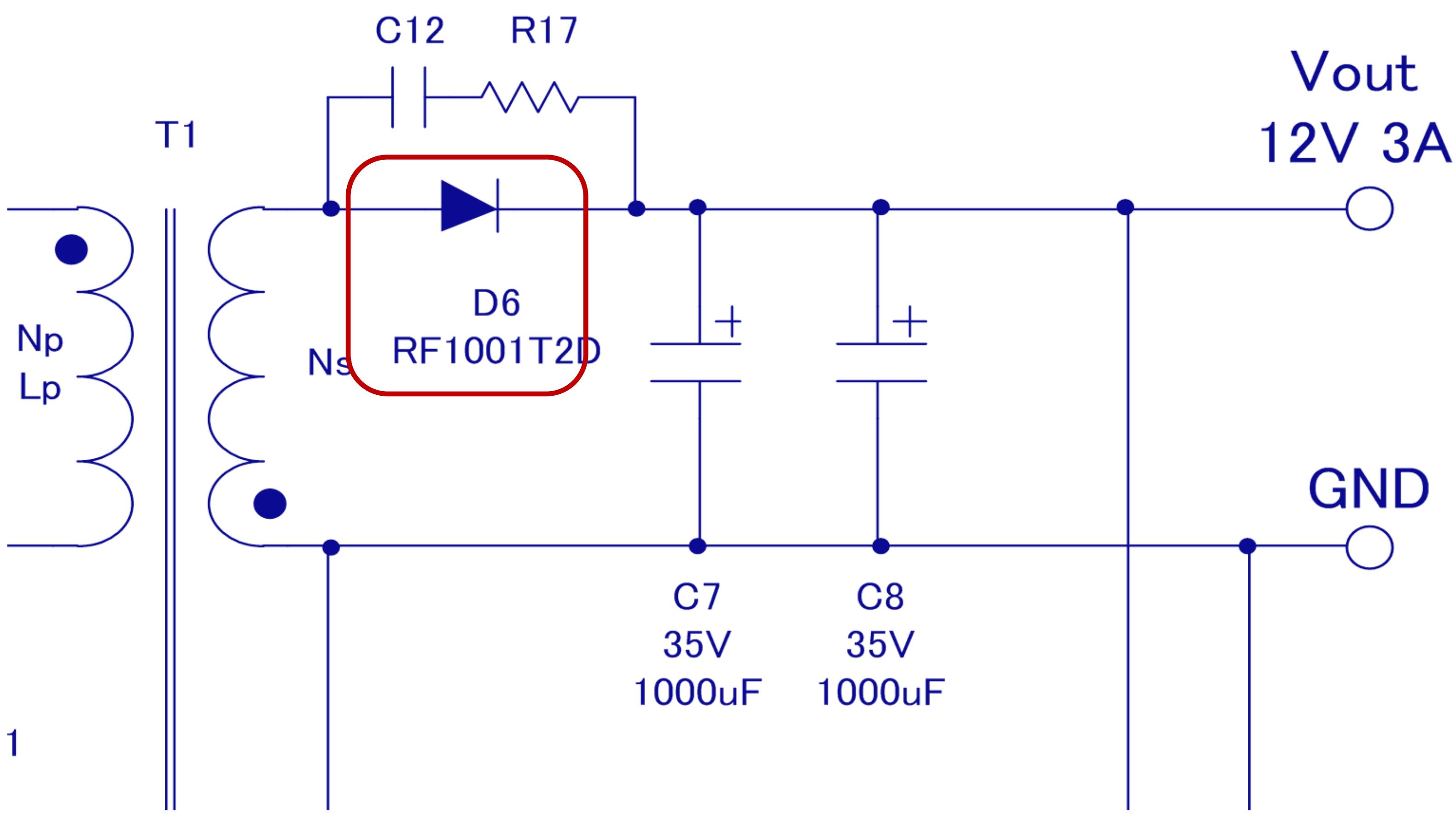
⇒ Considered as > 400V with a safe margin

4) D3 Selection

- A FRD should be used
- The withstand voltage is > Vds(max) of the MOSFET

- Besides the Lleak of transformer, the surge voltage is also affected by a PCB line inductance. Therefore the Vds should be checked at the actual circuit and modify the snubber circuit as needed.

④ Selection for Peripheral Parts: Output Rectifier Diode D6



4. Isolated Flyback Converter Design Example

ROHM SEMICONDUCTOR

④ Selection for Peripheral Parts: Output Rectifier Diode D6

- A fast output rectifier diode should be selected, e.g. a SBD (Schottky barrier diode) or a FRD (Fast recovery diode)

- Reverse Voltage to D6 : $Vdr = Vout(max) + VINmax \times \frac{Ns}{Np}$

- When Vout(max) = 12V + 5% = 12.6V : $Vdr = 12.6V + 372V \times \frac{7}{34} = 89V$

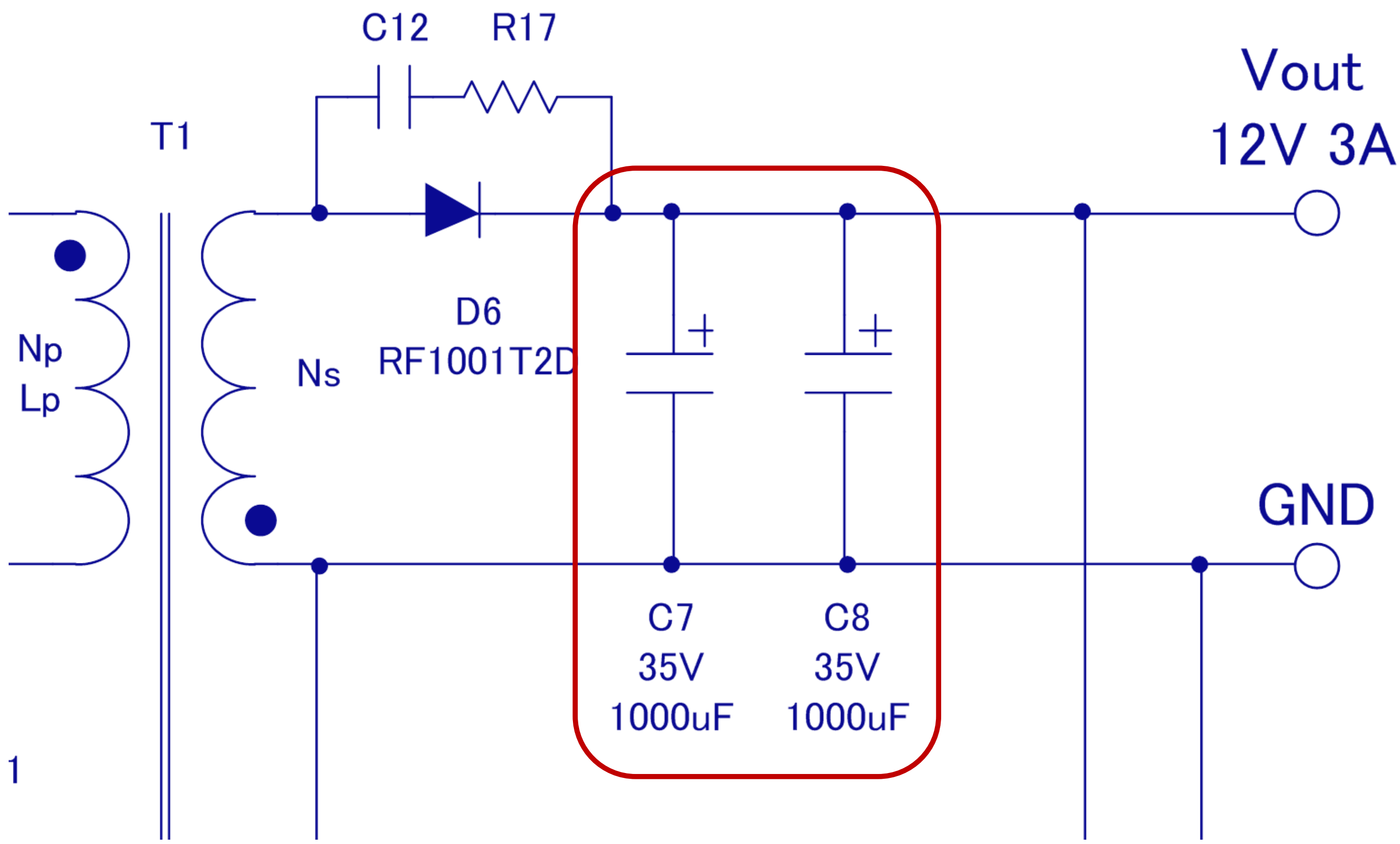
- Considered as 89.2V/0.7 = 127V with a safe margin ⇒ Select 200V Vdr diode

- The loss of diode (rough estimate) : Pd = Vf x Iout = 1V x 3A = 3W
  (Ex. RF1001T2D : 200V, 10A, TO-220F from ROHM)

- Recommended voltage margin is <70% and a current margin is < 50%

- Check the temperature raise at the actual circuit and review the diode selection or heat radiating by a heat sink as needed.

④ Selection for Peripheral Parts: Output Capacitor C7 & C8



4. Isolated Flyback Converter Design Example

ROHM SEMICONDUCTOR

④ Selection for Peripheral Parts: Output Capacitor C7 & C8

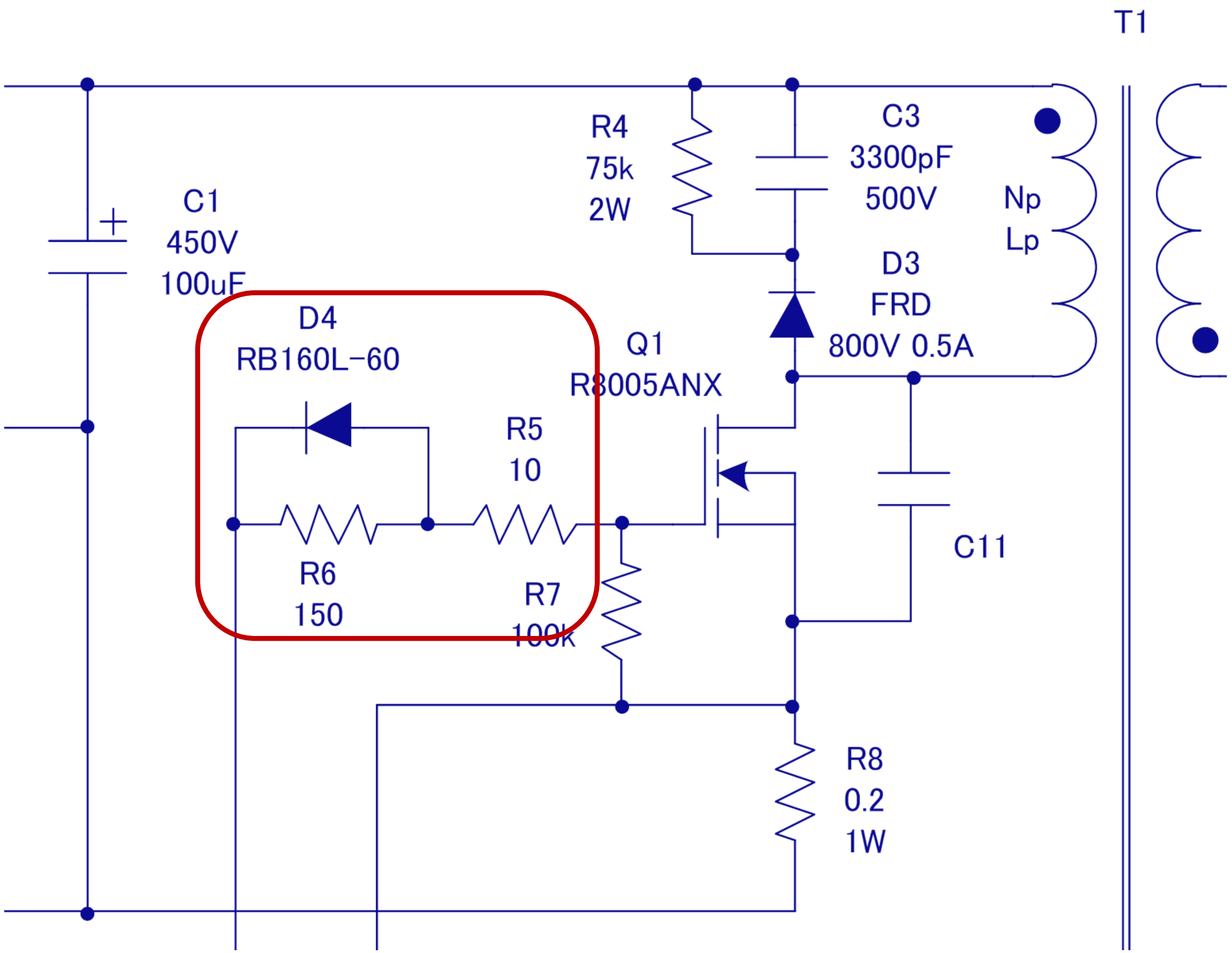
- The selection of the output capacitor is determined by a peak to peak ripple voltage ΔVpp and a ripple current which are allowed by output load devices
- When the MOSFET turns on, the output diode turns off, then the output capacitor provides a current to loads
- When the MOSFET turns off, the output diode turns on, then the output capacitor is charged and also provides a current to loads

Set ΔVpp=200mV: $Z\_C < \dfrac{\Delta Vpp}{Ispk} = \dfrac{0.2V}{12.1A} = 0.0165\ \Omega$ at 60kHz (fsw min)

- Converting the 60kHz impedance to 100kHz (Impedance of typical low-impedance electrolytic capacitor for switching is given at fsw = 100kHz) : $Z\_C < 0.0165\ \Omega \times \dfrac{60}{100} = 0.01\ \Omega$ at 100kHz
- Ripple current Is(rms) : $Is(rms) = Ispk \times \sqrt{\dfrac{1-Duty}{3}} = 12.1A \times \sqrt{\dfrac{1-0.406}{3}} = 5.384A$
- The withstand voltage of electrolytic capacitor is estimated 2x for the output voltage
  Vout x 2 = 12V x 2 = 24V ⇒ Considered as > 25V
- Selection example: Low-impedance 35V 1000μF electrolytic capacitor x 2 (parallel)

* Need to check the actual ripple voltage and ripple current at the actual circuit.

④ Selection for Peripheral Parts: MOSFET Gate Circuit R5, R6 & D4



4. Isolated Flyback Converter Design Example

ROHM SEMICONDUCTOR

④ Selection for Peripheral Parts: MOSFET Gate Circuit R5, R6 & D4

- The MOSFET gate circuit modifies the MOSFET losses and noise
- R5 and R6 modify the MOSFET turn-on speed
- R5 and the discharging diode D4 modify the MOSFET turn-off speed

  Selection example : R5 = 22Ω/0.25W, R6 = 150Ω, D4 = SBD 60V/1A
- When in DCM (discontinuous current mode), the turn-off switching loss is dominant and basically no switching loss at turn-on
- To reduce the turn-off switching loss, to lower R5 increasing the turn-off speed, but the switching noise increases due to the high speed current transient

* It is a trade-off between the MOSFET losses (= self-heat) and noise. Need to check the MOSFET temperature raise and noise level, and modify as needed

* Because a pulse current is passed through R5, need to check the pulse current tolerance of the resistor.

④ Selection for Peripheral Parts: Start-up/Shut-down AC Voltage Setting Resistor R2, R3

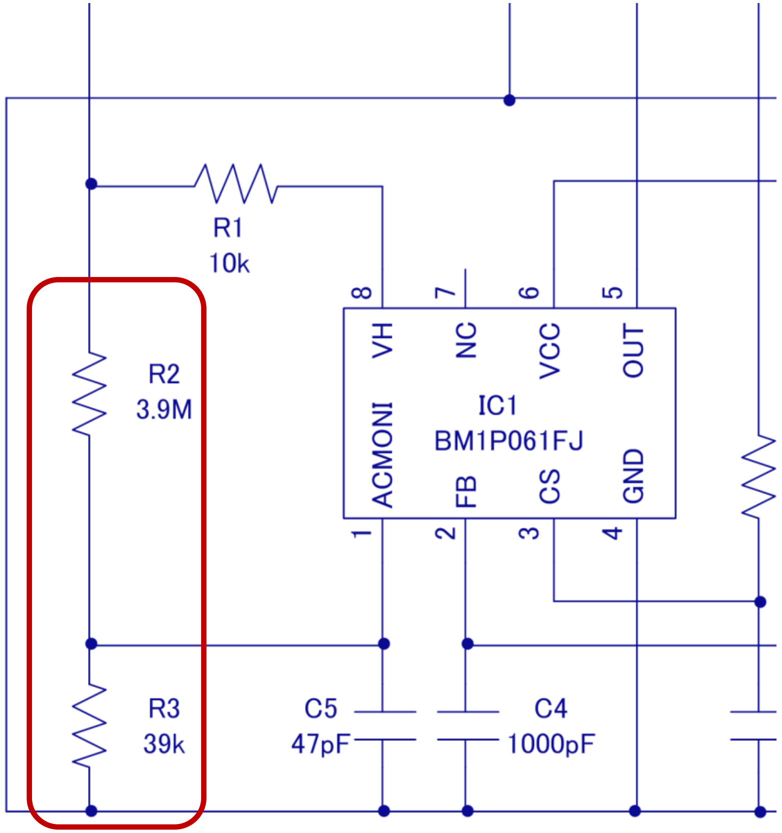
- The BM1PXXX includes the brown-out/in function which shut down the operation when the input AC voltage lower
- Set the start-up/shut-down threshold AC voltage using the ACMONI pin with R2 and R3

Threshold: raise 1.0V, down 0.7V

$$\text{On Voltage} = \frac{1.0\text{V}}{1.41} \times \frac{\text{R2} + \text{R3}}{\text{R3}}$$

$$\text{Off Voltage} = \frac{0.7\text{V}}{1.41} \times \frac{\text{R2} + \text{R3}}{\text{R3}}$$

⇒ Considered as R2 = 3.9MΩ and R3 = 39kΩ



Consequently:

On Voltage = 72VAC

Off Voltage = 50VAC

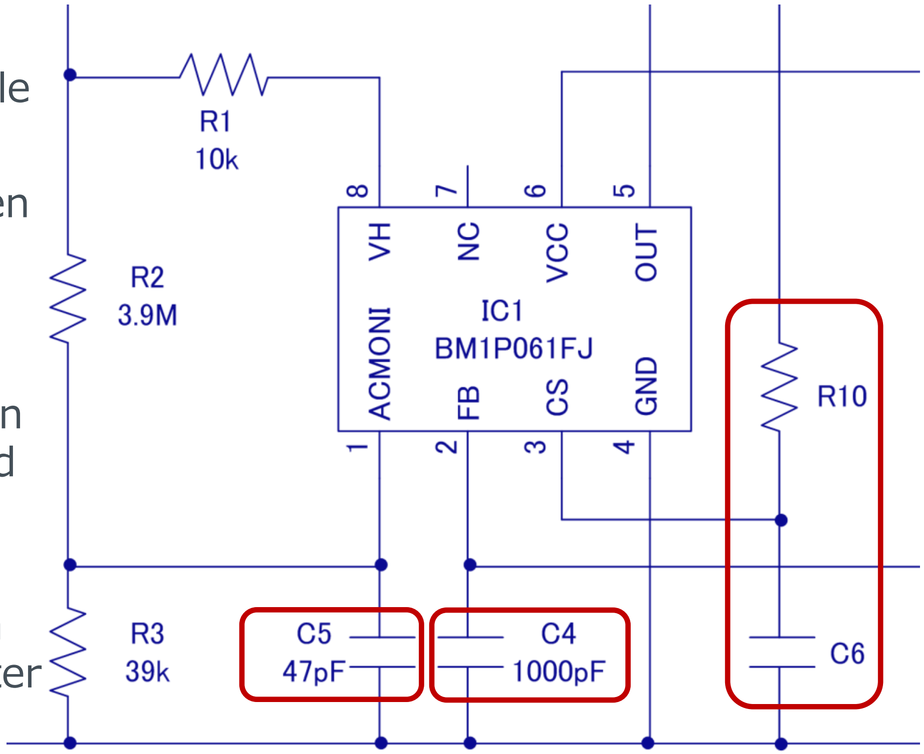
4. Isolated Flyback Converter Design Example

ROHM SEMICONDUCTOR

④ Selection for Peripheral Parts: Others

- C5 reduces a noise of the ACMONI pin and is used when the ACMONI pin voltage is unstable
- C4 settles the FB pin voltage and is used when the FB pin voltage is unstable (recommend 1000pF to 0.01μF)
- R10 and C6 are a RC filter which is used when a noise of the CS pin can't be enough reduced by the noise blanking function

* Recommend to insert R10 (around1kΩ) as a countermeasure for a surge voltage if the filter is not needed



ROHM SEMICONDUCTOR

④ Selection for Peripheral Parts: Others

- R14, R15 and R16 are output voltage setting resistors
  Vout is set by the following

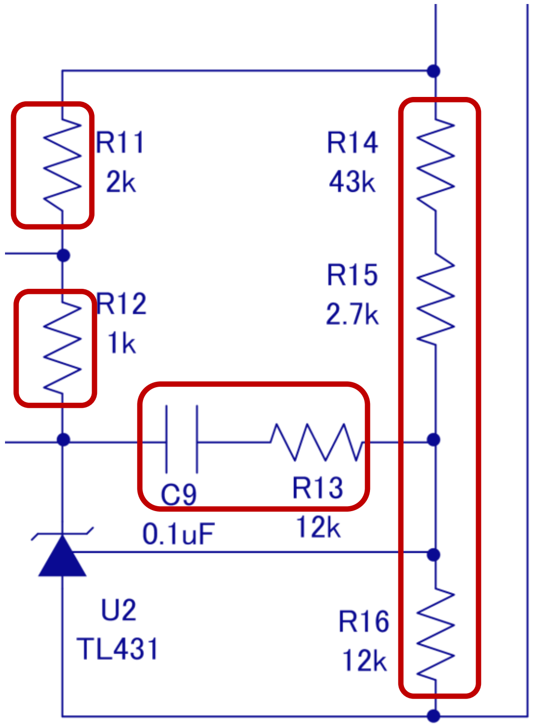
$$\text{Vout} = (1+\frac{\text{R14}+\text{R15}}{\text{R16}})\times \text{Vref} = (1+\frac{43\text{k}+2.7\text{k}}{12\text{k}})\times 2.495\text{V} = 12.0\ \text{V}$$

* 2.495V is the reference voltage(typ) of the shunt regulator U2

- C9 and R13 are a phase compensating circuit
  Considered as C9 = 0.1μF and R13 = 10k to 30kΩ
  Need to check at the actual circuit

- R11 is a limiting resistor for the control circuit current and 1k to 2kΩ is recommended

- R12 is the supply current setting resistor for the shunt regulator U2 TL431 which requires 1mA
  ⇒ R12 = Optical coupler's Vf / 1mA = 1V / 1mA = 1kΩ



4. Isolated Flyback Converter Design Example

⑤ EMI Countermeasures:

• Possible EMI Countermeasures:

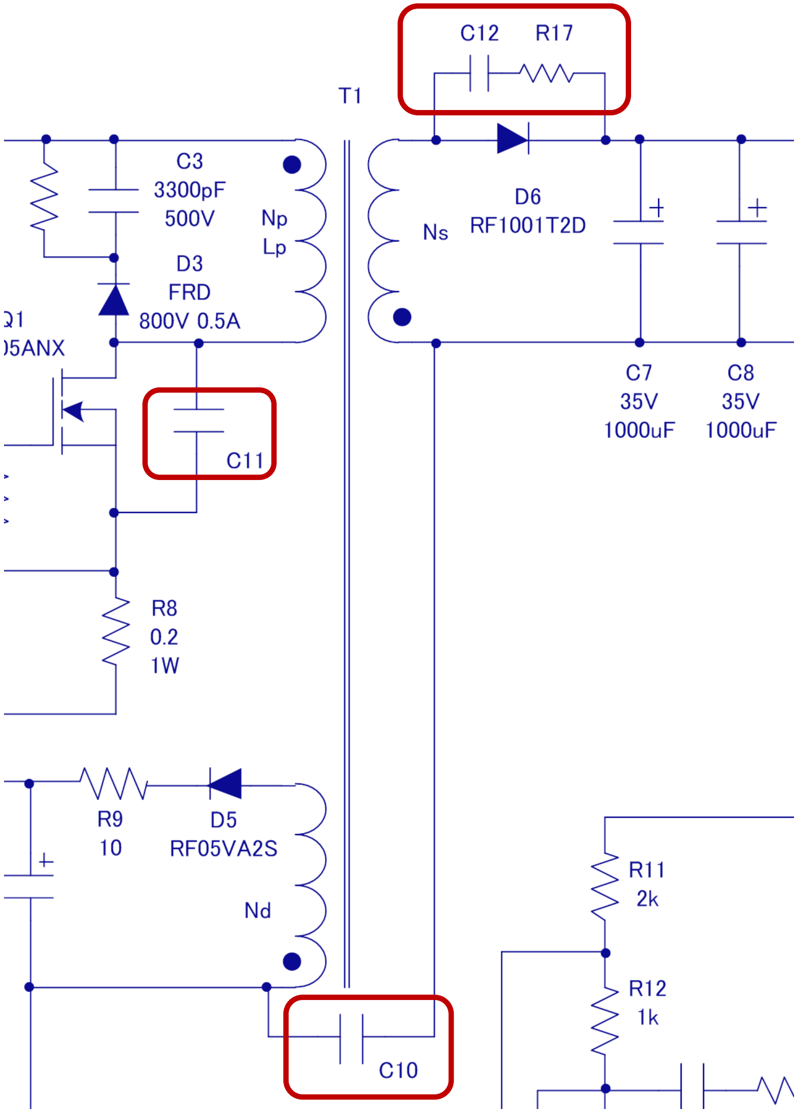
✓ Adding a filter to the input

✓ Adding a capacitor between the primary side and the secondary side
Ex. C10 = Y-Cap 2200pF

✓ Adding a capacitor between the drain and the source of the MOSFET
Ex. C11 = 10 to 100pF/1kV
* This makes losses of the MOSFET increase. Need to check the temperature raise of the MOSFET and modify as needed

✓ Adding a RC snubber to the diode D6
Ex. C12 = 1000pF/500V, R17 = 10Ω/1W

** All values are a reference value. Need to check actual EMI and modify as needed.



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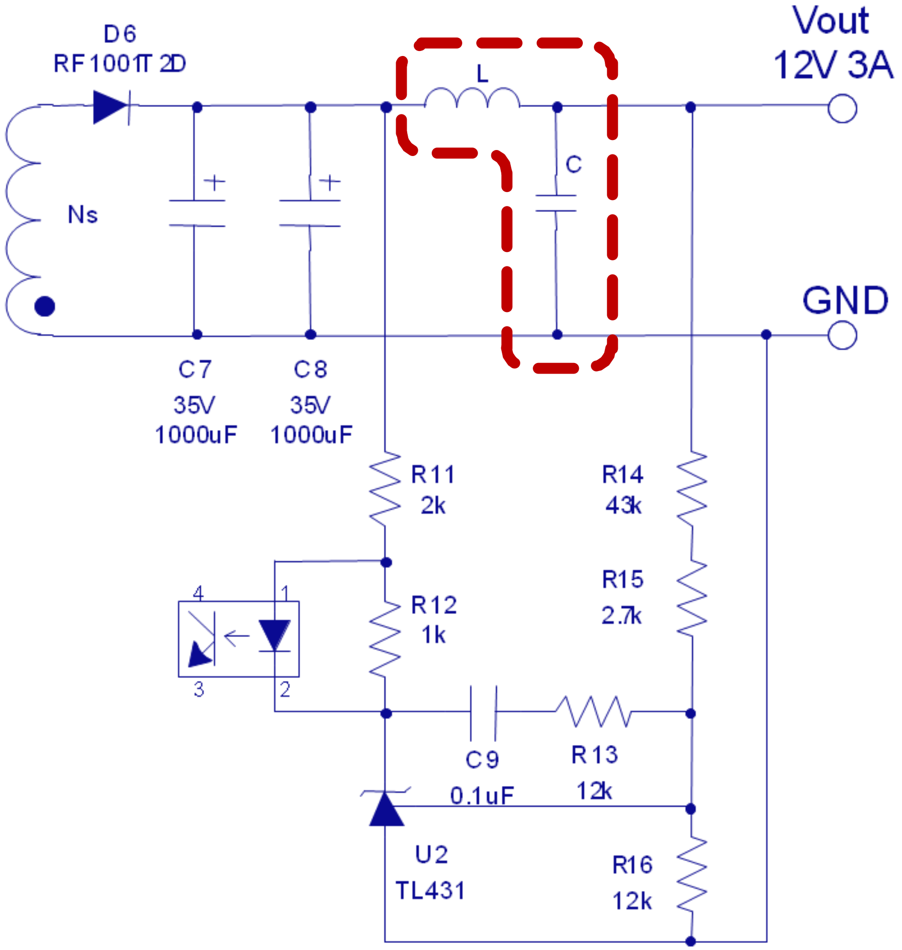
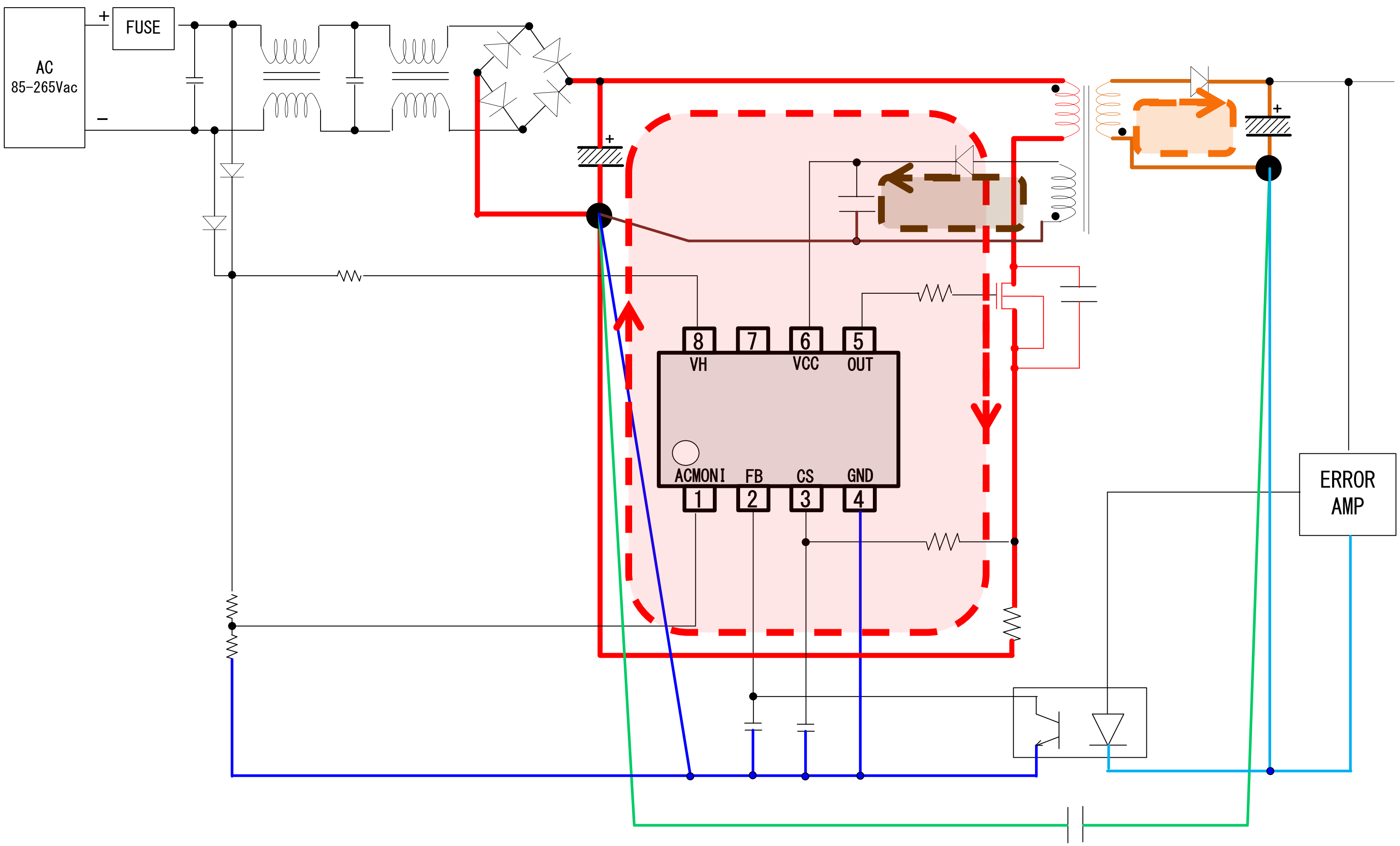
⑥ Output Noise Countermeasures:

- ✓ Adding a LC filter to the output
  Ex. L = 10μH, C10 = 10μ to 100μF

** All values are a reference value. Need to check actual output noises and modify as needed.



⑦ PCB Layout Example: Basic Considerations for a PCB Layout



⑦ PCB Layout Example: Basic Considerations for a PCB Layout

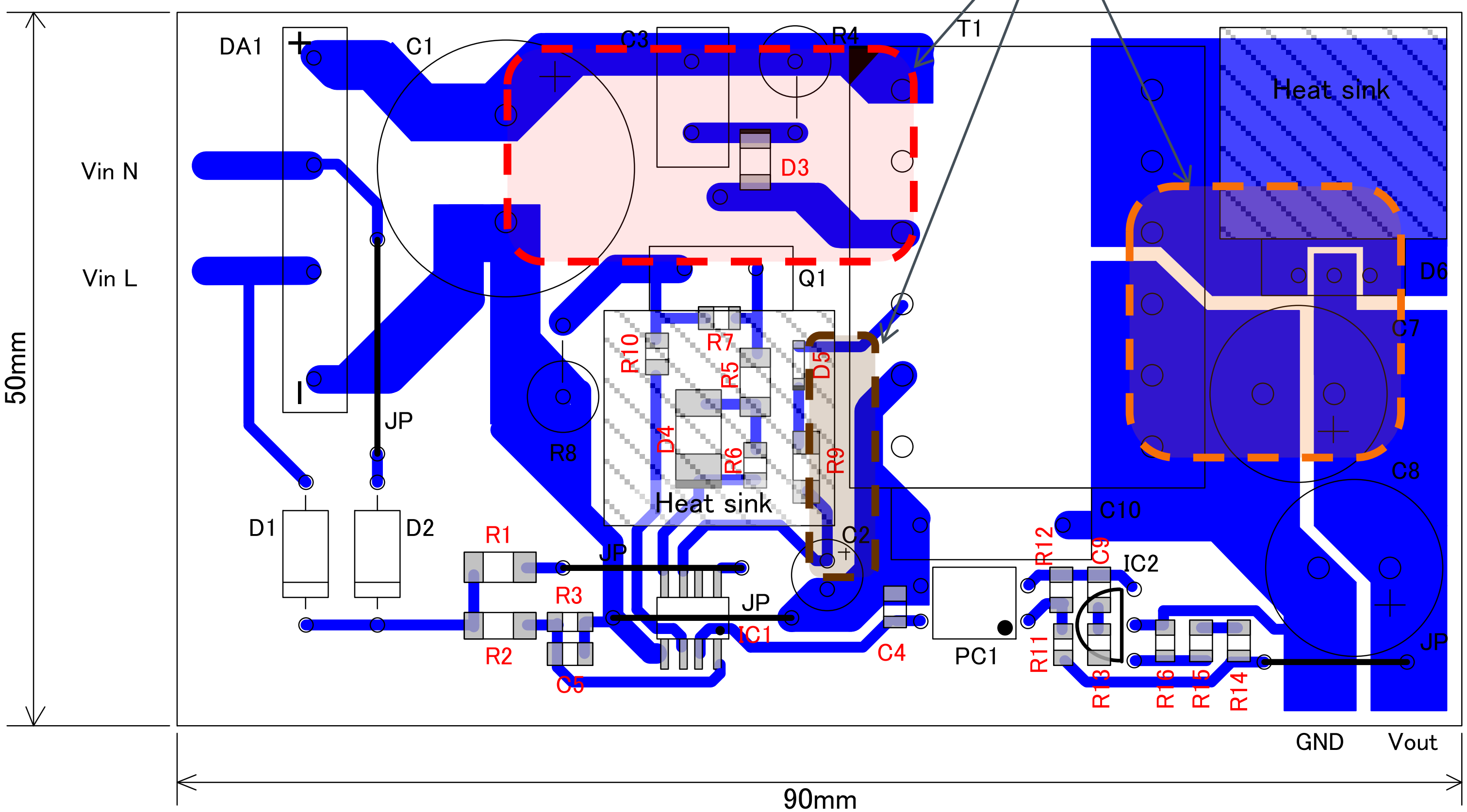
1. **The red lines should be wide and short as possible because they are large current paths and cause to occur ringing and losses.**
2. **Line loops by the red line should be small as possible.**
3. **The orange lines of the secondary side should also be wide and short as possible, and small line looping is allowed.**
4. **The brown line is a path of the VCC pin current and a separate routing is required because a switching current flows to the line.**
5. **Never route control lines of the IC under the transformer because the magnetic flux affects the control signal.**
6. The single-point grounding is recommend for the red, brown, blue and green lines.
7. The green lines are routed separately from the red and blue lines because a large current momentarily flows to the line as a diverting path of surge voltages from the secondary side to the primary side.
8. The blue lines are GND for control lines of the IC, therefore a large current doesn’t flow to the line however they are routed separately from the red, green and brown lines to avoid the affect of noises from the lines.

ROHM SEMICONDUCTOR

⑦ PCB Layout Example

- Single-sided PCB, leaded component side, surface mounted components is shown by red characters

Loops flow a switching current should be small as possible

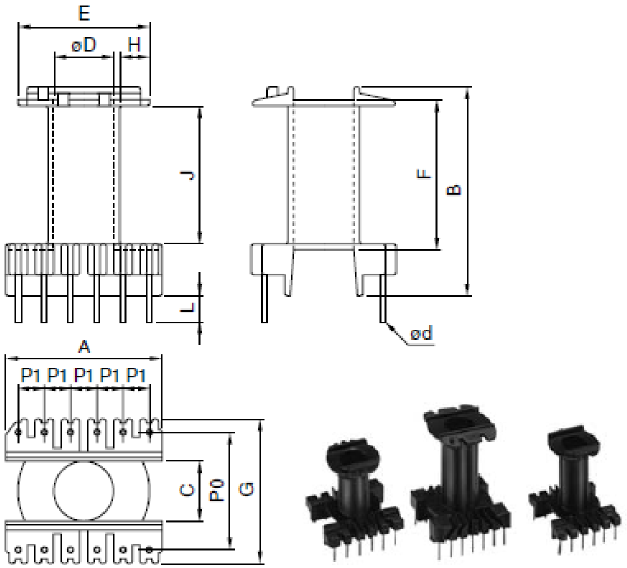


5. Transformer Design (Structure Design)

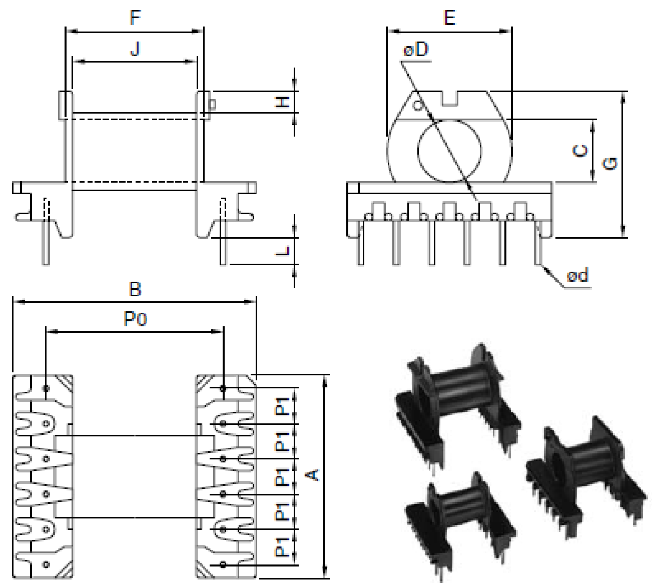
Transformer Specs

Core	JFE MB3 EER28.5A or Equal Quality
Lp	228 uH
Np	34 turns
Ns	7 turns
Nd	9 turns

Bobbin Selection



縦使用 Vertical use(V)



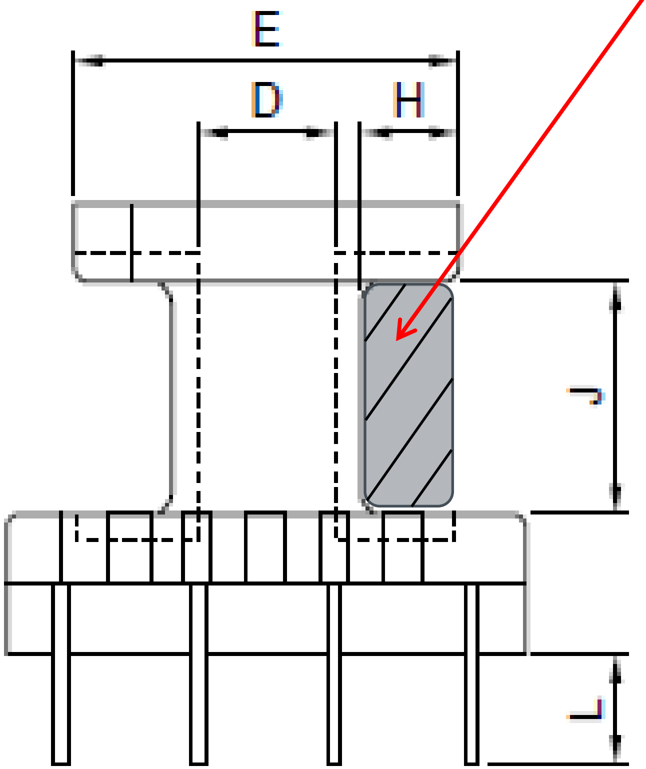
横使用 Horizontal use(H)

5. Transformer Design (Structure Design)

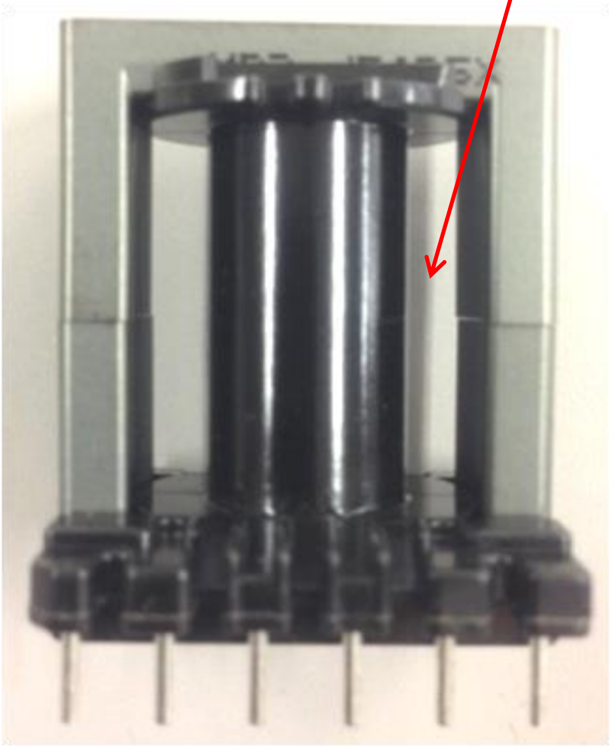
Transformer Spool

Calculate the available spool size from the specs of bobbin

JFE EER28.5: J = 16.6mm, H = 4mm

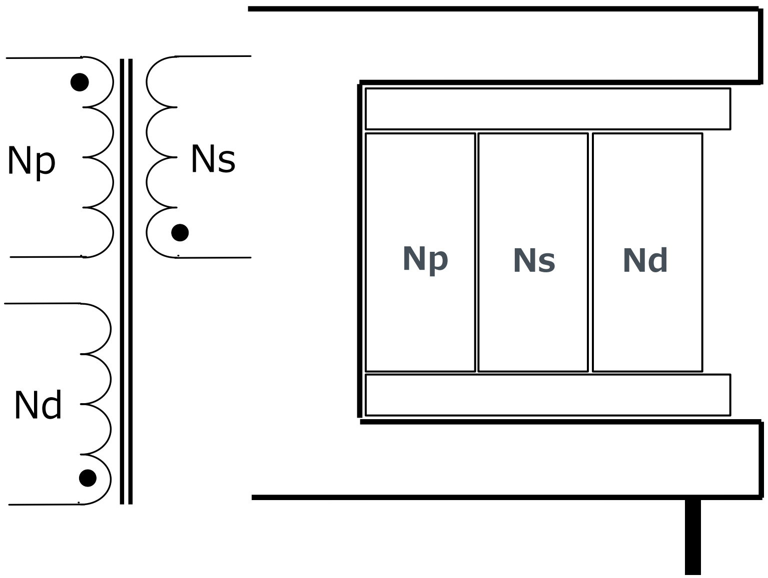


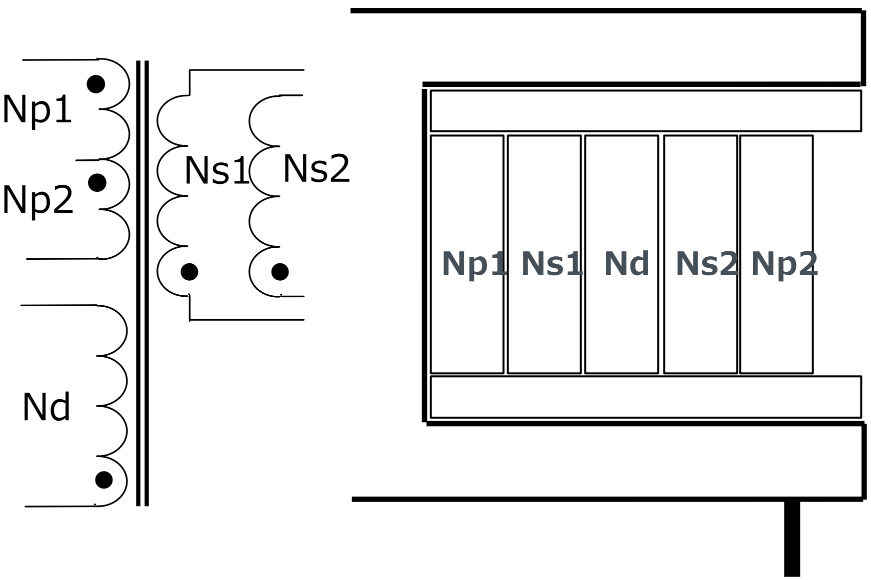
Available spool



5. Transformer Design (Structure Design)

Winding Structure





- Layer count: Low → Cost effective
- Poor coupling → Raise a surge voltage and losses
- Bobbin pin count: Low

- Layer count: Low → Care to the thickness of each winding
- Good coupling → Down a surge voltage and losses
- Bobbin pin count: High

5. Transformer Design (Structure Design)

Barrier Tape

・A constant creeping distance between the primary side and the secondary side of transformer is needed to conform to safety standards

⇒ Ensure a creeping distance by the width of barrier tape

・IEC60950 requires the following creeping distance at operating voltage 300V, Pollution Degree 2 and material group Ⅲa (CTI < 400):

Basic insulation: 3.2 mm
Reinforced insulation: 6.4mm (Basic insulation x 2) ← Required for the primary to the secondary

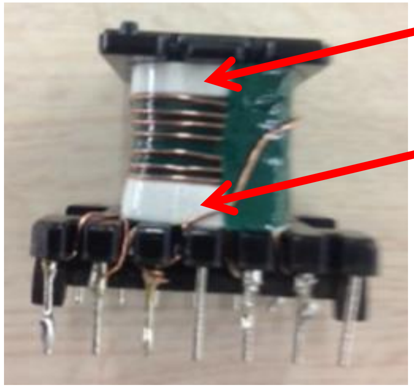
・linear interpolations between the nearest 2 points when the actual operating voltage is not the specified voltage

When the operating voltage is 270V,
250V = 2.5mm
300V = 3.2mm

⇒ Required creeping distance: 3mm x 2 = 6mm

・For a vertical-type bobbin:

The creeping distance becomes 1/2 due to no leads at the top side



5. Transformer Design (Structure Design)

Wire Selection:

・UEW (polyurethane copper wire) and PEW (polyester copper wire) are general

✓ Utilize a 3-layer insulated wire if ensure the required creeping distance

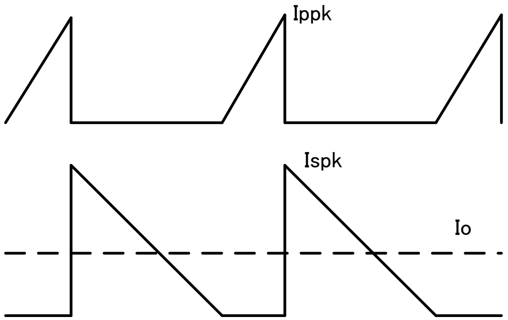
✓ Using a litz wire is effective to improve the characteristics

・Select a wire diameter fully to wind on a spool width of J ⇒ Improve the degree of coupling

・A fine wire has a smaller parasitic capacitance and the proximity effect and the skin effect are also smaller, however the current density becomes larger

⇒ Select a wire diameter with 4 to 8A/mm^2 current density

＊ Finally to check the temperature raise of transformer and modify as needed



< Current Density Without the Proximity and Skin Effect Considerations >

Ippk = 2.42A then Iprms = 0.74A and Ispk = 12.1A then Isrms=4.01A

Np Winding : Wire diameter = 0.4mm, Current density = 5.89A/mm^2

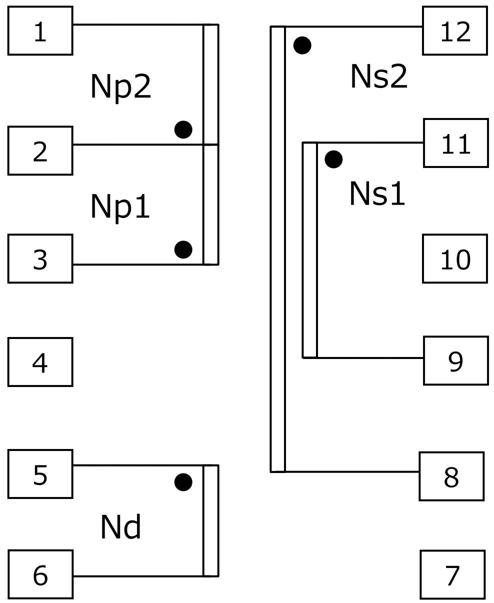
Ns Winding: Wire diameter = 0.45mm x2 and Ns1 // Ns2 then Current density = 6.31A/mm^2

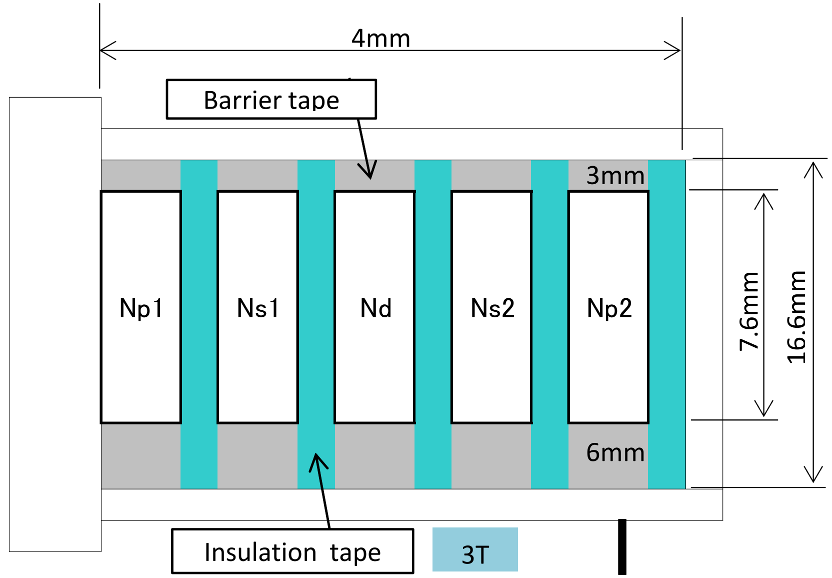
＊ Skin effect is the tendency for high-frequency currents to flow on the surface of a conductor.

＊ Proximity effect is the tendency for current to flow in other undesirable patterns, which are loops or concentrated distributions, due to the presence of magnetic fields generated by nearby conductors.

5. Transformer Design (Structure Design)

Connections, Layer Structure & Winding Specs





Coil	Terminal	Turns	Wire	Winding Method
Np1	‘3−2	17	2UEW 0.4	1 Layer FIT(密)
Insulation tape		3	t=25um	
Ns1	‘11−9	7	2UEW 0.45x2	1 Layer FIT(密)
Insulation tape		3	t=25um	
Nd	‘4−5	9	2UEW 0.35x2	1 Layer FIT(密)
Insulation tape		3	t=25um	
Ns2	‘12−8	7	2UEW 0.45x2	1 Layer FIT(密)
Insulation tape		3	t=25um	
Np2	‘1−2	17	2UEW 0.4	1 Layer FIT(密)
Insulation tape		3	t=25um	

Finished Diameter/ Thickness	Thickr	Winding Width
0.439	0.439	7.463
0.05	0.15	
0.49	0.49	6.86
0.05	0.15	
0.387	0.387	6.966
0.05	0.15	
0.49	0.49	6.86
0.05	0.15	
0.439	0.439	7.463
0.05	0.15	
	2.995	

5. Transformer Design (Structure Design)

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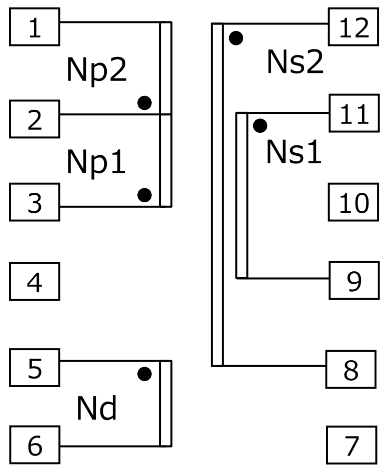
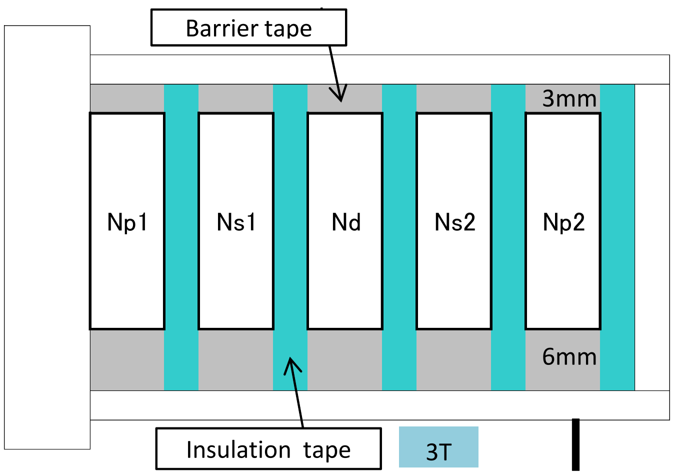
Transformer Specs





Core : JFE MB3 EER-28.5A or compatible
Bobbin : JFE BER28.5SP12 Vertical/Terminal Pins 6-6(12pins) or compatible
AL-Value : 197.2 nH/N^2
Inductance(1-3pin) : 0.228 mH±15%

Coil	Terminal	Turns	Wire	Winding Method
Np1	‘3-2	17	2UEW 0.4	1 Layer FIT(密)
Ns1	‘11-9	7	2UEW 0.45x2	1 Layer FIT(密)
Nd	‘4-5	9	2UEW 0.35x2	1 Layer FIT(密)
Ns2	‘12-8	7	2UEW 0.45x2	1 Layer FIT(密)
Np2	‘1-2	17	2UEW 0.4	1 Layer FIT(密)

Tolerance P-S : AC3.0KVrms 1 MIN. 2mA or AC3.6KVrms 1S 2mA
PS-CORE : AC1.5KVrms 1 MIN. 2mA or AC1.8KVrms 1S 2mA
IR : P-S, PS-CORE 100MΩ MIN. at DC 500V

Beginning of winding: Fixed with barrier tape
Beginning of winding: Fixed with barrier tape
Winding direction: Uniformed

Methods of Designing PWM Flyback Converter: AGENDA

1. Design Procedures for AC/DC Converter
   ①Determination of Power Supply Specs
   ②Selection for a Power Supply IC
   ③Design & Selection for Peripheral Parts
   ④Evaluation and Prototyping
   ⑤Production Model Design, Evaluation & Outgoing Inspection
2. Power Supply Specifications (design example)
3. Selection for a Power Supply IC
4. Isolated Flyback Converter Design Example
   ① Basics for Switching AC/DC Conversion
   ② Flyback Converter Operation
   ③ Transformer Design (Numeric Value Calculation)
   ④ Selection for Peripheral Parts
   ⑤ EMI Measures
   ⑥ Output Noise Measrues
   ⑦ PCB Layout Example
5. Transformer Design (Structure Design)