Input voltage autosensing
Provision for Standby mode operation
Partial Resonance Power Supply IC Module

MR2900 Series

2002/03/01

Tentative

Application Note

Shindengen Electric Manufacturing Co.,Ltd.

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Thank you   July 1st, 1995

Shindengen Electric MFG.CO.,LTD

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The values presented in this document are based on tentative specifications as of June 29th, 2001, and may change in future

1.1 Introduction

The MR2900 Series IC modules are designed for both 200V and autosensing input with a burst-mode switching function at micro-loads. These modules are of the partial resonance type, and are comprised of a switching device optimized for both 200V and autosensing power supply input, and a control IC. They are designed to provide the following power supply characteristics.

1.2 Characteristics

1. An ultra high-speed IGBT with 900V resistance ensures high efficiency and low noise at partial resonance.
2. An ultra high-speed IGBT with 900V resistance simplifies design for autosensing power supply input.
3. Very low power consumption at micro-loads (in burst mode).
4. Onboard start-up circuit eliminates the need for start-up resistors.
5. Soft drive circuit achieves low noise levels.
6. Excess current protection function (ton limit, primary current limit).
7. Excess voltage protection and thermal shut-down function.
8. Power supply circuits may be constructed with a minimum of external components.
9. The use of a full mold package provides benefits in insulation design.

1.3 Applications

TVs, displays, printers, VTR, DVD, STB, air-conditioners, refrigerators, and other electrical appliances, and office equipment.

1.4 Absolute Maximum Ratings and Reference Output Capacities

Model	Absolute maximum ratings		Maximum output capacity P_o [W]	
	Peak input voltage V_{in} [V]	Peak input current I_{in} [A]	Input voltage range	
			90V to 276VAC	180V to 276VAC
MR2920	900	7	100	150
MR2940		10	150	225

Maximum output capacity and input voltage range differ with design conditions.

1.5 Equivalent Circuit and Dimensions
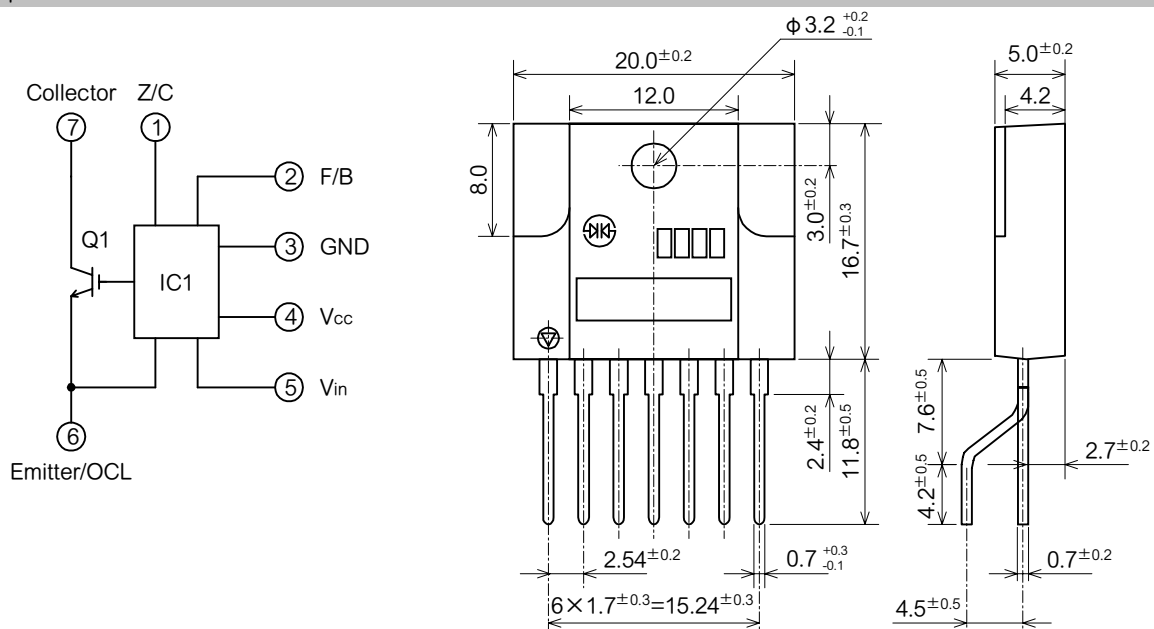
2.1 Block Diagram
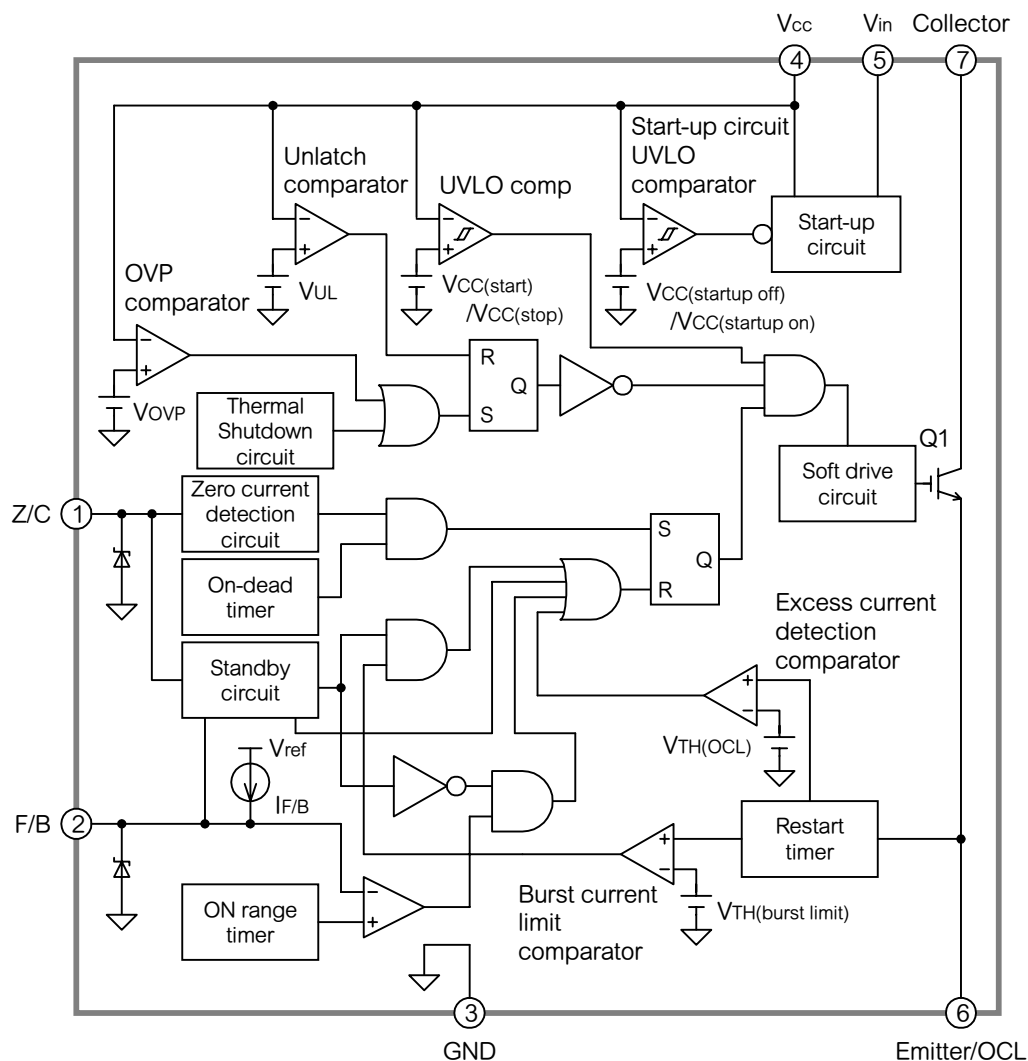
2.2 Pin Function Description

Pin number	Abbreviation		Description
1	Z/C	Trigger input pin	Zero detection voltage: 0.35V Standby: Up to 4.5V in standby mode.
2	F/B	Feedback signal input pin	$t_{on(min)}$ to $t_{on(max)}$: 1.5V to 4.5V/0 μs to 25 μs Standby: Oscillation stopped at up to 0.8V. Standby: Oscillation started at 1.8V or higher.
3	GND	GND pin	
4	V_{cc}	IC power supply pin	Oscillation start voltage: $V_{cc} \geqq 14V$ Oscillation stop voltage: $V_{cc} \leqq 8.5V$ Excess voltage latching voltage: $V_{cc} = 20V$
5	V_{in}	Start pin	Current supplied $V_{in} \rightarrow V_{cc}$ at start-up Start-up circuit OFF: $V_{cc} \geqq 14V$ Start-up circuit ON: $V_{cc} \leqq 7.6V$
6	Emitter /OCL	Main switching device emitter and current detection pin	Excess current detection threshold: 0.6V Excess current detection threshold at standby: 50mV
7	Collecter	Main switching device collector pin	

3.1 Start-up Circuit

In conventional start-up circuits employing a start-up resistor, current continues to flow following power supply start-up, thus wasting power and reducing efficiency, particularly during standby.
See Fig.3.1 Comparison of Start-up Circuits - Conventional Start-up Circuit.

In the MR2000 Series start-up circuit the start-up current is supplied from the input voltage at power supply start-up, and is shut-off when the power supply is in operation.

The start-up circuit supplies a current of 12mA (typical) from the IC internal constant current source until the voltage at the V_{CC} pin reaches 14V (typical). This current is consumed internally in the IC as well as being used as the charging current for the condenser connected externally between the V_{CC} pin and GND.
This design allows a stable start-up only minimally dependent upon input voltage.
When the voltage at the V_{CC} pin reaches 14V (typical) the start-up circuit is disconnected, the start-up current no longer flows and oscillation begins simultaneously.
The current consumed in the IC is then supplied from the control coil. See Fig.3.1 Comparison of Start-up Circuits - MR2000 Start-up Circuit.

【Conventional Start-up Circuit】

Start-up current

IC

Start-up current flows even during steady-state operation, resulting in losses.

【MR2000 Start-up Circuit】

Start-up current switched off following start-up, thus eliminating the need for start-up resistors.

Vin pin
⑤

V_{CC}(startup off) /V_{CC}(startup on)
14.5V/7.2V

Control coil

Vcc pin
④

Fig.3.1 Comparison of Start-up Circuits

In the case of an instantaneous power failure or a load short, oscillation is stopped when the voltage at the V_{CC} pin reaches 8.5V, and when this voltage drops to 7.6V the start-up circuit operates again and the voltage at the V_{CC} pin then begins rising. See Fig.3.2.

Incorporation of the functions described above improve efficiency, particularly during standby, and reduces the number of start-up resistors required, thus reducing the overall number of components.
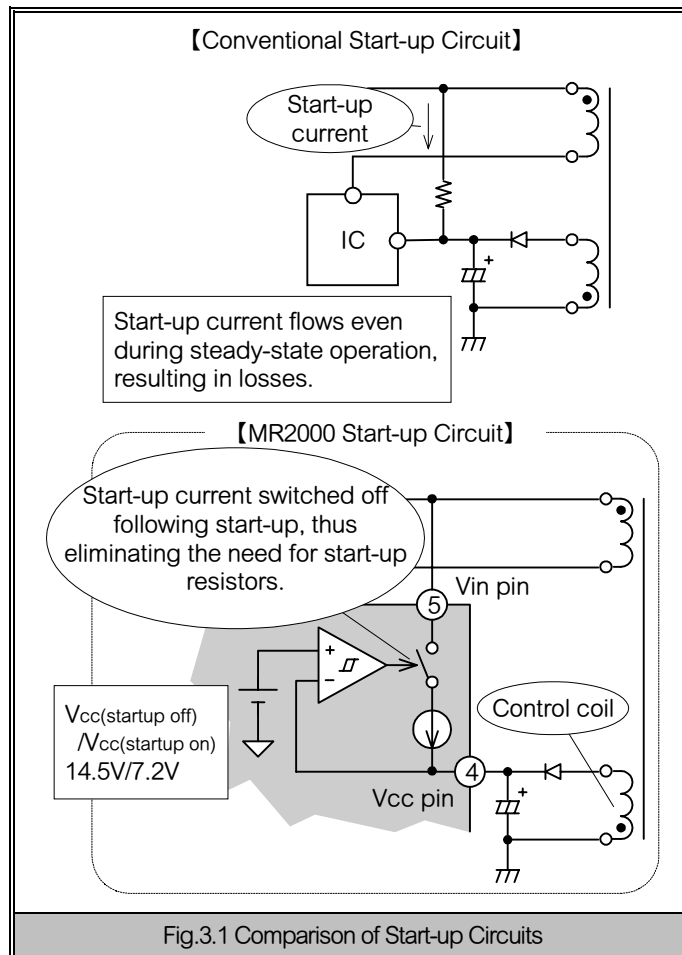
V_{CC}(startup off)
=V_{CC}(Start)
=14.0V
【Vin】

V_{CC}(stop)
=8.5V

V_{CC}(startup on)
=7.6V
【Vcc】

【Vce】
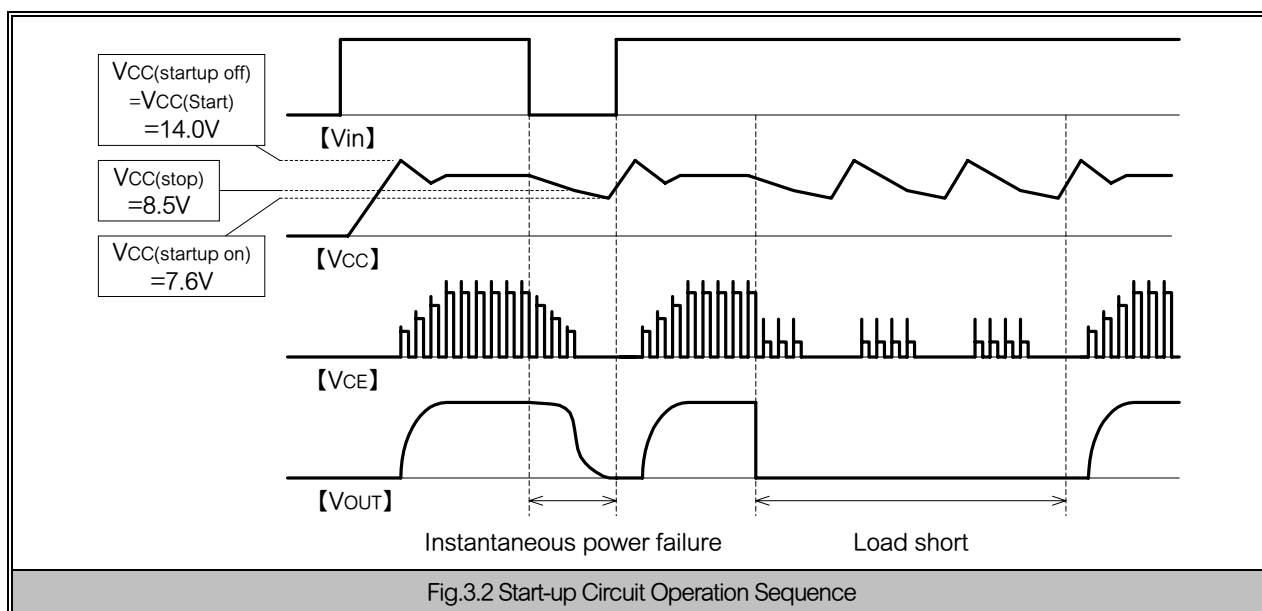
【Vout】

Instantaneous power failure   Load short

Fig.3.2 Start-up Circuit Operation Sequence

3.2 On-trigger Circuit

The MR2000 Series employs current-critical operation to detect energy bursts at the secondary side of the main transformer and switch on the main switching device.

Energy discharge timing is detected at the negative edge of the control coil voltage waveform (0.2V in the diagram at right), and the main switching device switched on for current-critical operation.

The on-trigger detection voltage (0.2V) incorporates a 50mV hystersis to increase noise resistance.

0.2V

【$V_{Z/C}$】

【I_C】

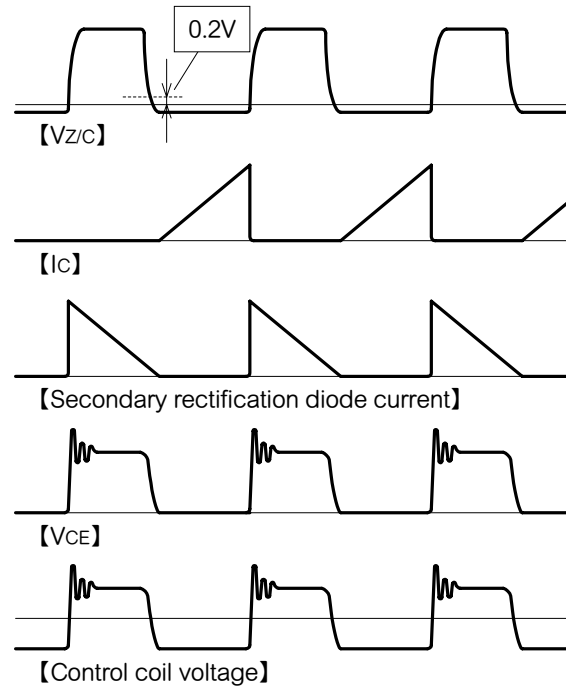【Secondary rectification diode current】

【V_{CE}】

【Control coil voltage】

Fig.3.3 On-trigger Operation Sequence

3.3 Partial Resonance

In current-critical switching power supplies (RCC), damping begins at the resonance frequency (determined by the primary inductance L_P of the main transformer and the resonating condenser C) when the secondary current in the circuit formed by connecting the resonating condenser between the collector and GND of the main switching device reaches 0A.

The discharge current of the resonating condenser flows through the primary coil and returns energy to the input. Adjustment of the CR time constant applied to the Z/C pin (see diagram at right) allows the main switching device to be turned on at the trough of the damping voltage waveform, thus permitting a reduction in turn-on losses.

In a circuit using partial resonance, the energy stored in the resonating condenser during the OFF period of the main switching device is returned to the input, thus permitting a reduction in turn-on losses. This allows the connection of a large-capacity condenser between the collector and GND of the main switching device, and thus permits a reduction in noise.

The use of partial resonance is effective in permitting a simple circuit configuration with improved efficiency and noise reduction.

On timing delayed with CR time constant.

Collector pin

Emitter/OCL pin

7

Z/C pin

6

1

R

Resonating condenser

3

GND pin

C

Turn-on delay

【V_{CE}】

Damping begins at the resonance frequency determined by LP and C.
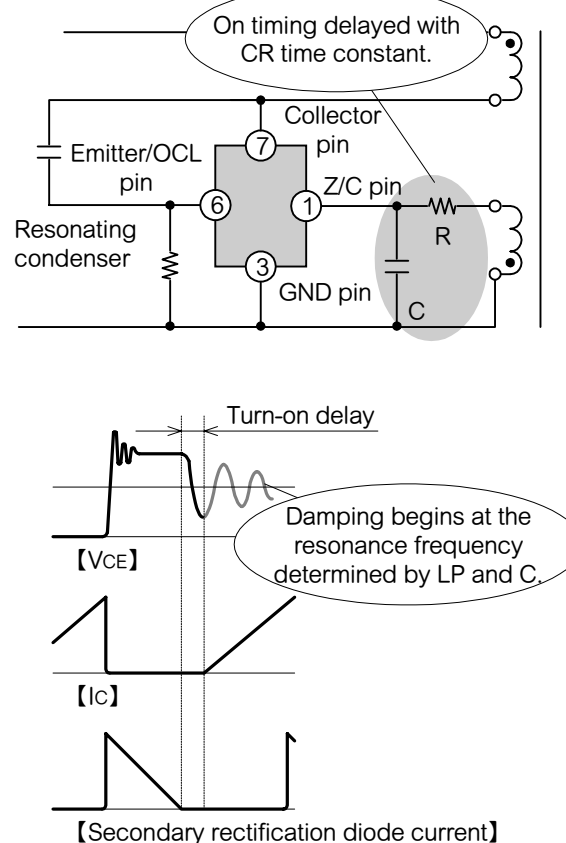
【I_C】

【Secondary rectification diode current】

Fig.3.4 Partial Resonance

3.4 Standby Mode Control (patent applied for)

The MR2000 Series is able to switch between two methods of output voltage control - normal operation and the standby mode, in a single power supply.
The standby mode supported by this IC employs the burst method for intermittent operation under light loads to reduce oscillation frequency and switching losses, and is effective in reducing the standby input voltage under micro-loads.

A unique characteristic of this IC is the use of the burst mode for intermittent operation without stopping IC control, and thus minimizing output ripple.
The Z/C pin is clamped to a voltage of 4.5V (typical) or less by an external signal to allow selection of standby mode control. The standby mode is cleared (ie restored to the normal mode) by clearing the clamp voltage on the Z/C pin, and applying a voltage of 4.5V (typical) or higher.

In normal operation the ON range of the main switching device is controlled in a linear manner in relation to voltage variation at the F/B pin, while in standby mode operation the Emitter/OCL pin current detection threshold value is switched from 0.6V for the normal mode to 0.05V for the standby mode.
The collector current is fixed at a peak value by the current detection threshold value, and the burst mode is selected.

Burst mode control is such that oscillation occurs when the voltage at the F/B pin is 1.8V (typical) or higher, and is stopped when this voltage is 0.8V (typical) or lower.

As output voltage control in the standby mode fixes the drain current peak value for each oscillation cycle, the duty ratio of the oscillating and non-oscillating intervals is varied to ensure a constant voltage.
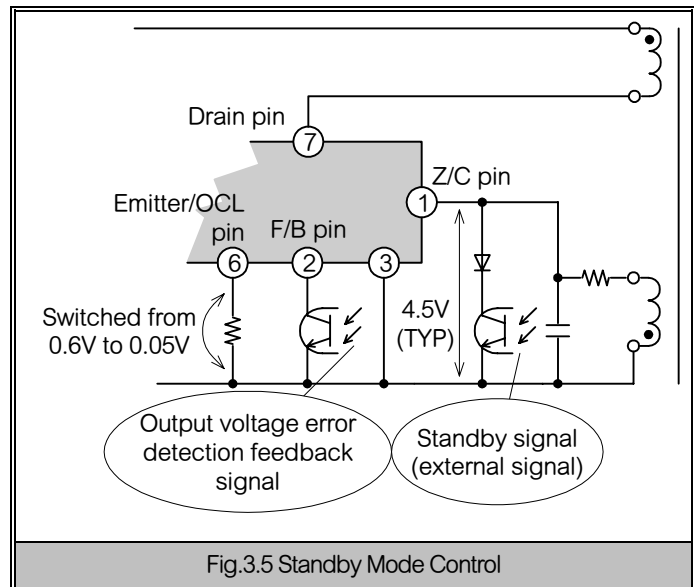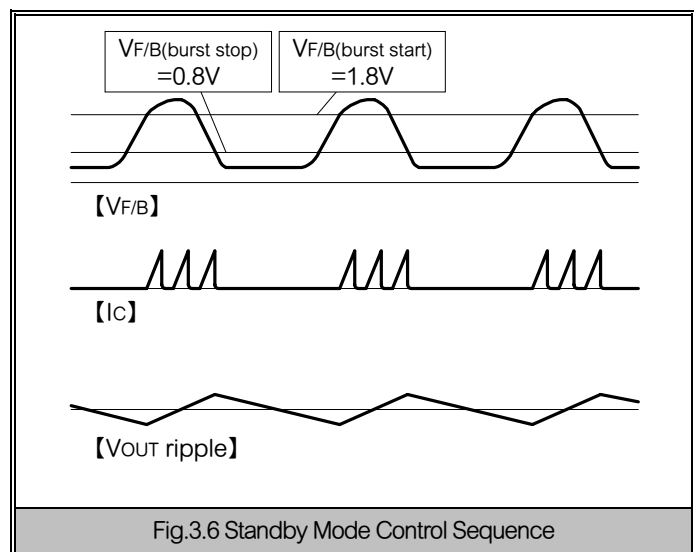

Fig.3.5 Standby Mode Control
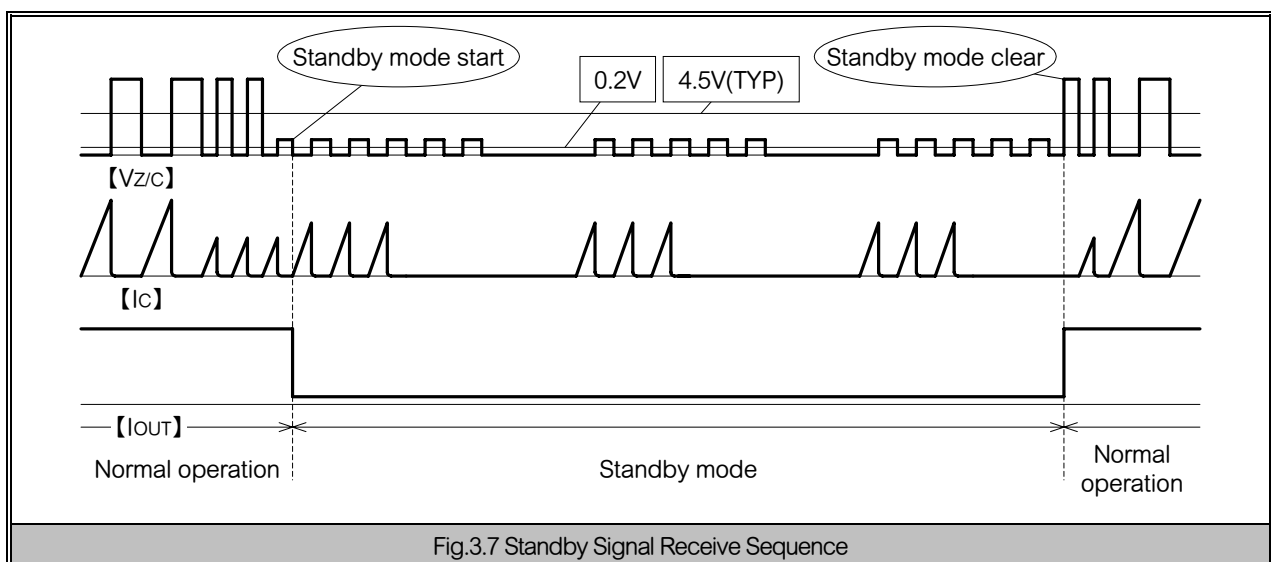

Fig.3.6 Standby Mode Control Sequence

Fig.3.7 Standby Signal Receive Sequence

3.5 Output Voltage Control (normal operation)

The MR2000 Series controls output voltage with the ON range proportional to the voltage at the F/B pin.

When the voltage at the F/B pin is 1.5V the ON range is 0μs, and is controlled in a linear manner so that when the voltage is 4.5V the ON range is 25μs. A current of 200μA=IF/B (typical) flows at the F/B pin, and the impedance of the photocoupler transistor connected externally between the F/B pin and GND is varied with the control signal from the secondary output detection circuit, thus controlling the ON range of the main switching device to produce a constant voltage.

The maximum ON range is adjusted by setting the maximum value for the voltage at the F/B pin using a resistor connected externally between the F/B pin and GND.
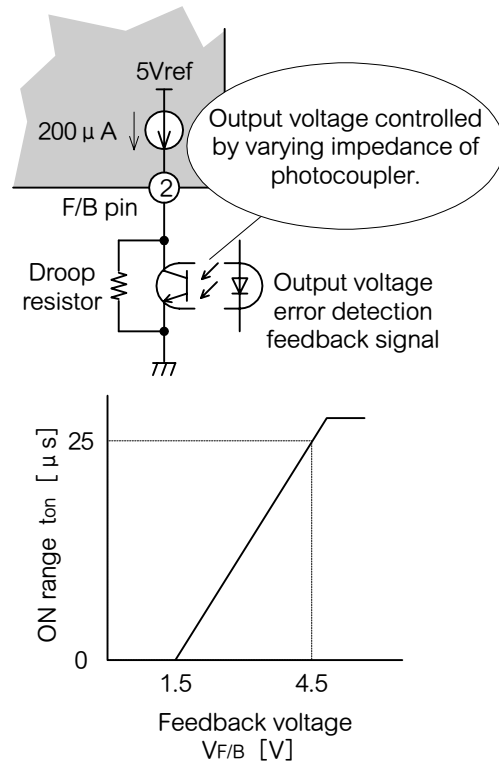
Fig.3.8 Output Voltage Control

3.6 Soft Drive Circuit (patent applied for)

The MR2000 Series supplies the main switching device gate drive voltage from two separate drive circuits.

A voltage exceeding the threshold value for the main switching device is supplied from the first drive circuit at the leading edge of the drive voltage waveform to switch on the main switching device with the optimum timing.
The drive voltage is then supplied gradually by the second drive circuit (see Fig.3.9).

Supply of drive voltage in this manner reduces drive losses, as well as reducing noise due to gate charge current and discharge current when the resonating condenser is switched on.

Fig.3.9 Comparison of Drive Circuits

3.7 Circuit for Load Shorts

The MR2000 Series is designed so that when droop occurs under excessive load, output voltage drops, and control coil voltage drops in proportion.

When the control coil voltage falls below 4.5V (typical) the standby mode is selected and the Emitter/OCL pin threshold voltage changes from 0.6V to 0.05V, thus limiting the collector current to approximately 1/10th of its previous value.

This design permits a reduction in the stress on the MR2000 Series IC in the case of a load short, and control of the short-circuit current in the secondary diode and load circuit.

4.5V(TYP)

【V$_{Z/C}$】

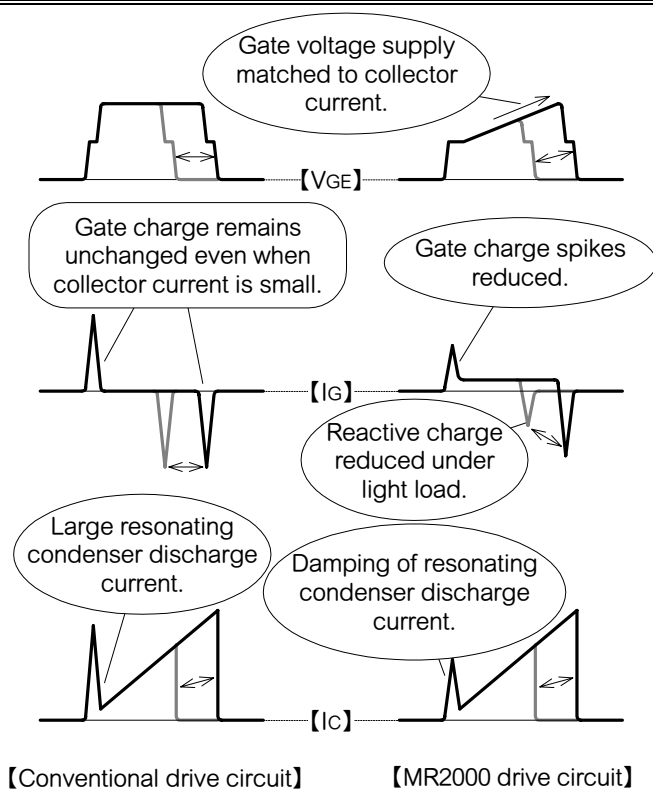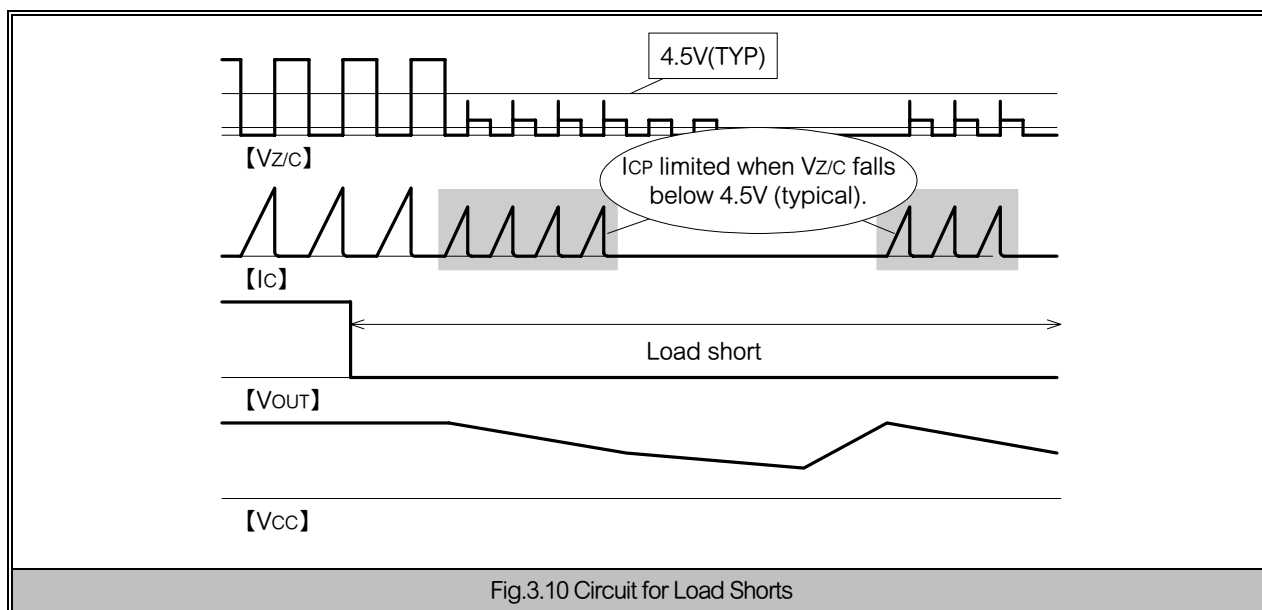I$_{CP}$ limited when V$_{Z/C}$ falls below 4.5V (typical).

【I$_C$】

Load short

【V$_{OUT}$】

【V$_{CC}$】

Fig.3.10 Circuit for Load Shorts

3.8 Collector Pin (pin 7)

The collector pin on the main switching device.

The transformer is designed, and the resonating condenser adjusted, to ensure that V$_{CE(max)}$ is less than 900V.

Depending upon input conditions, the collector pin may be subjected to reverse bias for a period during partial resonance.

This IC employs an ultra high-speed IGBT in the main switching device. This device differs from MOSFET devices in that it has no body diode structure, thus requiring connection of an external high-speed diode between the Collector and Emitter/OCL pins.

3.9 Thermal Shut-down Circuit (TSD)

The MR2000 Series incorporates a thermal shut-down circuit.

The onboard IC is latched at 150°C (typical) and oscillation is then stopped.

Unlatch is achieved by momentarily dropping the voltage at the V$_{CC}$ pin to V$_{UL}$ (unlatch voltage) or lower.

3.10 Over-voltage Protection Circuit (OVP)

The MR2000 Series incorporates an over-voltage protection circuit (OVP).

Latching occurs when the control coil voltage exceeds 20V (typical), and secondary output over-voltage protection then operates indirectly.

Unlatch is achieved in the same manner as for the overheat protection circuit.

3.11 Malfunction Prevention Circuit (patent applied for)

The use of current-critical operation in the MR2000 Series ensures that the main transformer does not become saturated provided the droop setting is optimized.

On the other hand, at start-up, and in the case of a load short, the output voltage is very much less than the set voltage.
As the control coil voltage is proportional to the output voltage it also reaches an extremely small value, and the on-trigger timing may be incorrectly detected due to the ringing voltage while the device is OFF and switched on before the current-critical point.

To counter this problem, the MR2000 Series incorporates a circuit to prevent on-trigger malfunction at start-up, and in the case of a load short. This function disables the on-trigger for a period of 2.7 μs (typical) after the main switching device in the IC is switched OFF (on-dead time). This prevents incorrect detection due to the ringing voltage while the device is OFF.

This design permits detection of the point at which the transformer secondary current is 0A at start-up, and in the case of a load short. The main switching device is then switched on at this point, allowing abnormal oscillation to be controlled.

On-trigger disabled during this period.
2.5 μs
0.2V
【V$_{Z/C}$】
【I$_C$】
【Secondary rectification diode】
Enlarged view
【V$_{Z/C}$】
【I$_C$】
【Secondary rectification diode】
【V$_{CE}$】
【V$_{OUT}$】
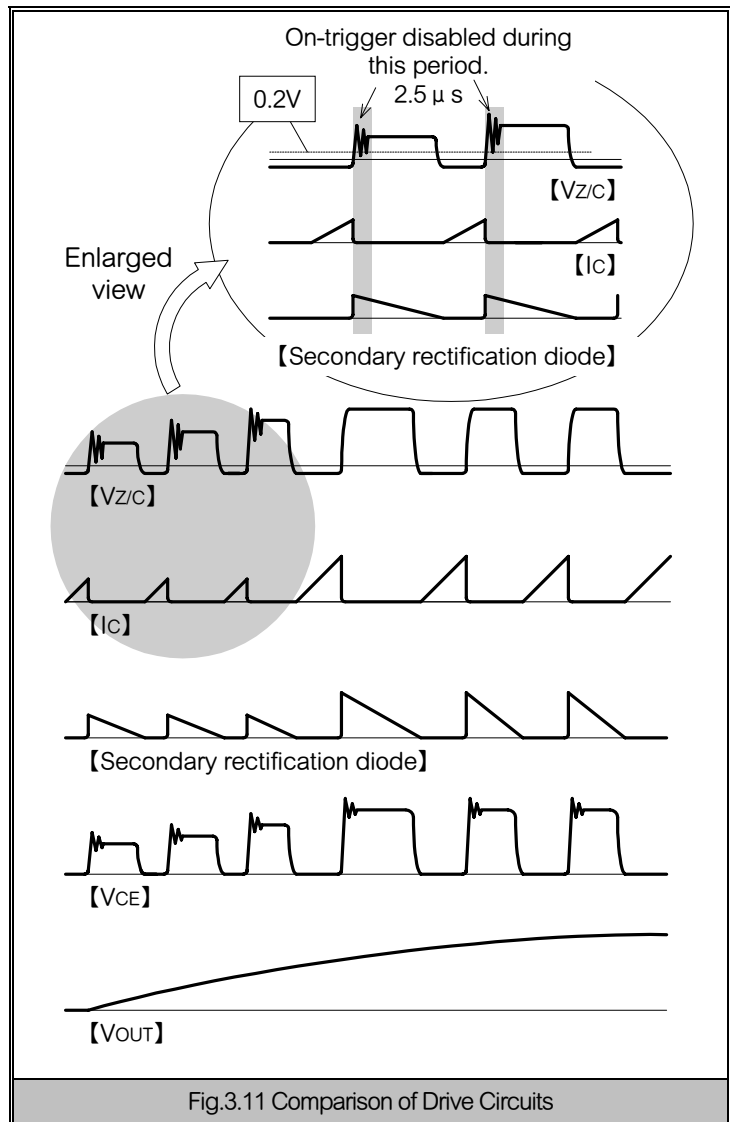
Fig.3.11 Comparison of Drive Circuits

3.12 Over-current Protection Circuit

A current detection resistor is connected between the Emitter/OCL pin and GND to detect current between the emitter of the main switching device and the emitter current detection pin.

During stable operation the main switching device current is limited by pulse-by-pulse operation with the 0.6V threshold value.
The leading edge clamp function prevents malfunctioning and thus prevents incorrect detection at turn-on.

During standby, the 50mV threshold value is selected and the oscillation noise from the transformer due to burst oscillation is reduced.

Body diode
Collector pin
⑦
Resonating condenser
Emitter/OCL pin
⑥
Current detection resistor

Fig.3.12 Current Detection Resistor

5.1 Design Flow Chart

```
        ┌─────────────────────────────┐
        │   Specifications determined │
        └─────────────────────────────┘
                     ⇩
        ┌─────────────────────────────┐      ┌──────────────────────────────────────────┐
   ┌───▶│   Main transformer design   │──────│ Refer to:                                │
   │    └─────────────────────────────┘      │ 5.2 Main Transformer Design Procedure    │
   │                 ⇩                        │ 5.3 Main Transformer Design Examples      │
   │    ┌─────────────────────────────┐      └──────────────────────────────────────────┘
   ├───▶│ Selection of primary circuit│──────┌──────────────────────────────────────────┐
   │    │         components          │      │ Refer to:                                │
   │    └─────────────────────────────┘      │ 5.4 Selection of Constants for Peripheral │
   │                 ⇩                        │     Components                            │
   │    ┌─────────────────────────────┐      └──────────────────────────────────────────┘
Reexamination
   ├───▶│       Cooling design        │
   │    └─────────────────────────────┘
   │                 ⇩
   │    ┌─────────────────────────────┐
   ├───▶│      Trial manufacture      │
   │    └─────────────────────────────┘
   │                 ⇩
   │    ┌─────────────────────────────┐
   └────│     Operational checks      │
        └─────────────────────────────┘
   Problems found    ⇩   No problems
        ┌─────────────────────────────┐
        │         Completion          │
        └─────────────────────────────┘
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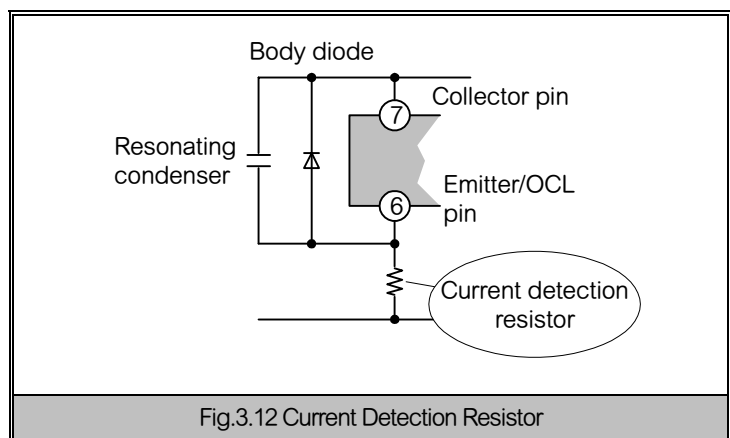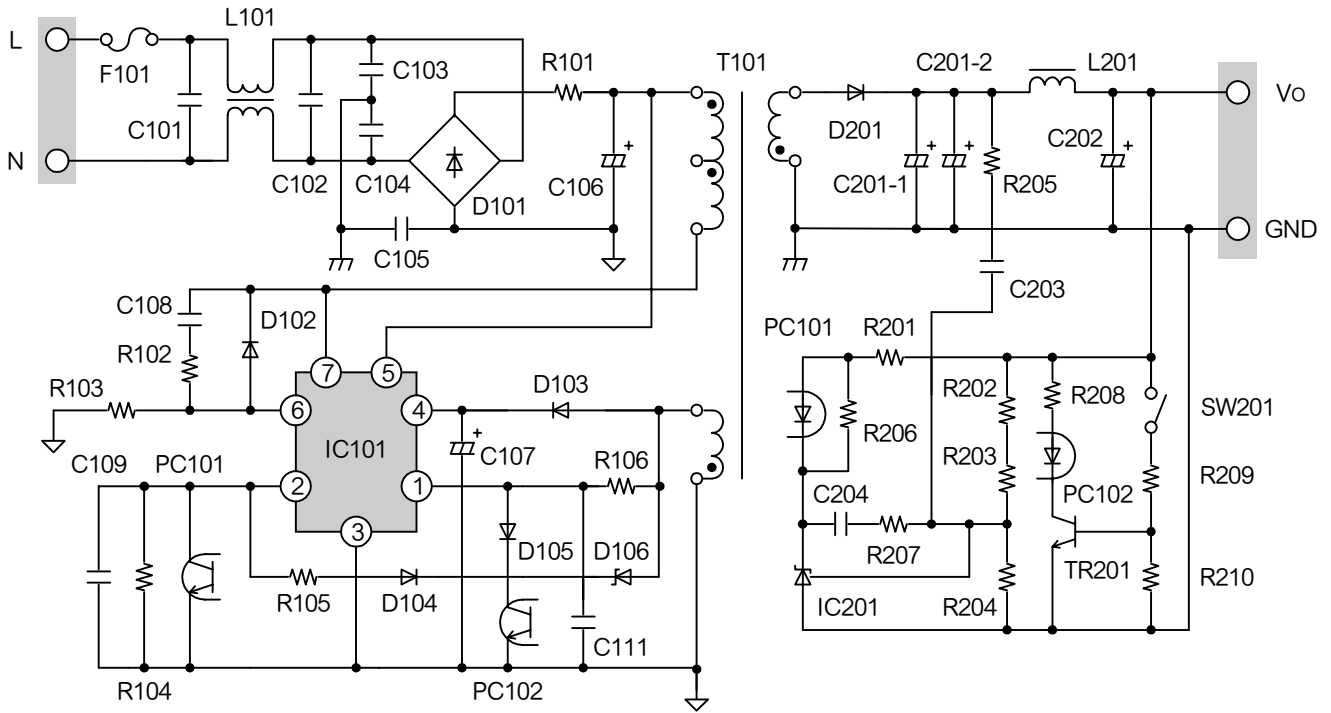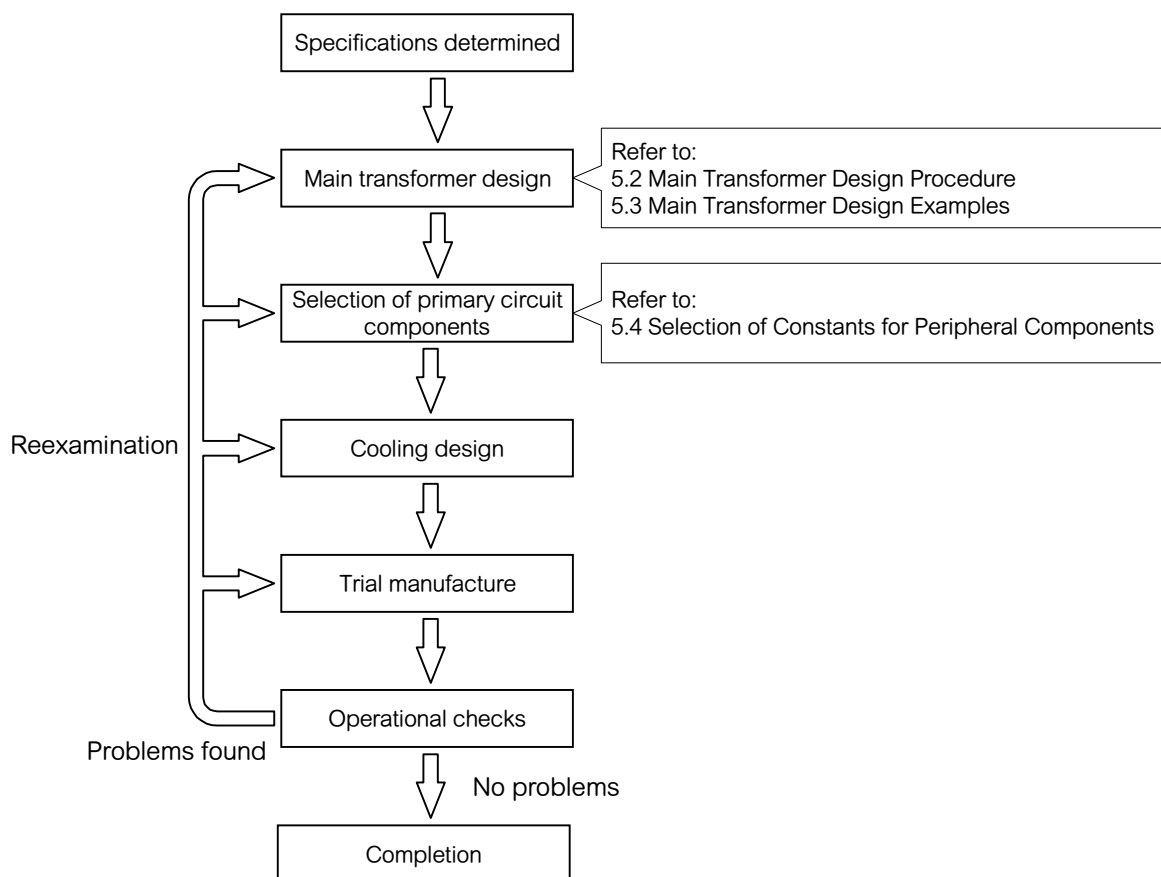
5.2 Main Transformer Design Procedure

This design procedure provides an example of an electrical design procedure.
Ensure that design of insulation materials, insulation configuration, and structure are in accordance with the necessary safety standards as determined by the relevant authorities.

5.2.1 Standard Design Conditions

	Abbreviation	Unit	Reference value
Minimum input voltage	$V_{AC(min)}$	V	—
Rated output voltage	V_o	V	—
Rated output current	I_o	A	—
Maximum output current	$I_{o(max)}$	A	—
Efficiency	η		0.80～0.85
Minimum oscillation frequency	$f_{(min)}$	kHz	25k～50kHz
Duty ratio	D		0.50～0.70
Control coil voltage	V_{NC}	V	15～17V
Effective cross-sectional area of transformer core	A_e	mm^2	—
Magnetic flux density variation	ΔB	mT	250～320mT
Coil current density	α	A/mm^2	4～6A/mm^2

Note that the above values are for reference only, and should be adjusted to suit load conditions.

5.2.2 Standard Design Calculations

1	Minimum DC input voltage	$V_{DC(min)} = 1.2 \times V_{AC(min)}$	[V]
2	Maximum DC input voltage	$V_{DC(max)} = \sqrt{2} \times V_{AC(max)}$	[V]
3	Oscillation cycle	$T_{(max)} = \dfrac{1}{f_{(min)}}$	[s]
4	Maximum ON period	$t_{on(max)} = \dfrac{D}{f_{(min)}}$	[s]
5	Maximum OFF period	$t_{off(max)} = \dfrac{N_{S1} \times V_{DC(min)} \times t_{ON(max)}}{N_P \times (V_{O1} + V_{F1})} + t_q$	[s]
6	Resonance period	$t_q = \dfrac{2\pi\sqrt{L_P \times C_q}}{2}$	[s]
7	Maximum load power	$P_{O(max)} = V_O \times I_{O(max)}$	[W]
8	Maximum output power (reference value)	$P_L = 1.3 \times P_{O(max)}$	[W]
9	Peak collector current	$I_{CP} = \dfrac{2 \times P_L}{\eta \times V_{DC(min)} \times D}$	[A]
10	Primary coil inductance	$L_P = \dfrac{V_{DC(min)} \times t_{on(max)}}{I_{CP}}$	[H]
11	Number of turns in primary coil	$N_P = \dfrac{V_{DC(min)} \times t_{on(max)} \times 10^9}{\Delta B \times A_e}$	[Turn]
12	Core gap	$I_g = \dfrac{4\pi \times 10^{-10} \times A_e \times N_P{}^2}{L_P}$	[mm]

The gap I_g is the center gap value.
Review transformer core size and oscillation frequency and redesign if I_g is 1mm or greater.

13	Number of turns in control output coil	$N_{S1} = \dfrac{(V_{O1} + V_{F1}) \times N_P \times (\dfrac{1}{f_{(min)}} - t_{on(max)} - t_q)}{V_{DC(min)} \times t_{on(max)}}$	[Turn]
14	Number of turns in non-control output coil	$N_{S2} = N_{S1} \times \dfrac{V_{O2} + V_{F2}}{V_{O1} + V_{F1}}$	[Turn]
15	Number of turns in control coil	$N_C = N_{S1} \times \dfrac{V_{NC} + V_{FNC}}{V_{O1} + V_{F1}}$	[Turn]

Consider the secondary diode forward voltage for each output when determining the number of turns in an output coil.
V_{FNC} is the control coil voltage rectification diode forward voltage.
The reference value for determining the control coil voltage $V_{NC(min)}$ is 15V to 17V.

If the $V_{NC(min)}$ value is too small, start-up characteristics may deteriorate and start-up may become difficult.
If the $V_{NC(min)}$ value is too large, the over-voltage latch stop voltage V_{OP} is able to be reached easily.
Check the $V_{NC(min)}$ voltage in an actual circuit during the design process to determine its optimum value.

16	Primary coil size	$A_{NP} = \dfrac{2 \times \sqrt{D} \times P_O}{\alpha \times \sqrt{3} \times \eta \times V_{DC(min)} \times t_{on(max)} \times f_{(min)}}$	[mm²]
17	Secondary coil size	$A_{NS} = \dfrac{2 \times \sqrt{1 - D - (t_q \times f_{(min)})} \times I_O}{\alpha \times \sqrt{3} \times (t_{off(max)} - t_q) \times f_{(min)}}$	[mm²]

A_{NC}=0.2mm dia. is recommended for the N_C coil for ease of calculation.

5.3 Main Transformer Design Examples

5.3.1 Initial Setup

Input voltage	AC90~276V
Efficiency	85%
Oscillation frequency at droop	29.6kHz
Duty ratio	T_{ON}/T=0.655

Rated output	V_{O1} : DC135V, 0.45A	Total output 81.2W
	V_{O2} : DC35V, 0.40A	
	V_{O3} : DC16V, 0.40A	
Droop output	110.36W (rated output x 1.36)	

5.3.2 Primary Inductance (LP) Calculations

Primary inductance (L_P) calculated using equations 1, 4, 9, and 10 in 5.2.2.

$V_{DC(min)} = 1.2 \times V_{AC(min)} = 1.2 \times 90 = 108$ [V]

$t_{on(max)} = \dfrac{D}{f_{(min)}} = \dfrac{0.655}{29.6 \times 10^3} = 22.13$ [μs]

$I_{CP} = \dfrac{2 \times P_L}{\eta \times V_{DC(min)} \times D} = \dfrac{2 \times 110.36}{0.85 \times 108 \times 0.655} = 3.67$ [A]

Substitute

$L_P = \dfrac{V_{DC(min)} \times t_{on(max)}}{I_{CP}} = \dfrac{108 \times 22.13 \times 10^{-6}}{3.67} = 651.24$ [μH]

Primary inductance L_P =0.65mH.

⚠️ Ensure that $t_{on(max)}$ is 29 μs or less.

⚠️ Droop output (rated total output x 1.36) calculated as P_L

5.3.3 Calculation of Number of Turns in Primary Coil (NP), and Gap (Ig)

The number of turns in the primary coil is calculated using equation 11 in 5.2.2.
Specifications require the use of PC40 EER39L steel in the transformer core.
Substitute A_e=130mm² and △B=310mT in equation 11.

$N_P = \dfrac{V_{DC(min)} \times t_{on(max)} \times 10^9}{\Delta B \times A_e} = \dfrac{108 \times 22.13 \times 10^{-6} \times 10^9}{310 \times 130} = 59.3 \cong 59$ [Turn]

The gap (Ig) is calculated using equation 12 in 5.2.2.

$I_g = \dfrac{4\pi \times 10^{-10} \times A_e \times N_P{}^2}{L_P} = \dfrac{4 \times 3.14 \times 10^{-10} \times 130 \times 59^2}{0.65 \times 10^{-3}} = 0.87$ [mm]

The number of turns in the primary coil is N_P=59, and the gap I_g=0.87mm.
The gap (I_g) calculated above is a reference value.
During trial manufacture, adjust the gap (I_g) in relation to the value found in the calculations, and ensure that it is appropriate to the primary inductance value.

⚠️ The maximum rating for △B for PC40 at 100°C is 390mT.
△B has been derated to 310mT in this example.

⚠️ The number of turns has been rounded to the nearest integer, however this value may be adjusted as necessary.

5.3.4 Calculation of Number of Turns in Secondary Coil (N_{S1})

The number of turns in the secondary coil is calculated using equation 13 in 5.2.2.

$$N_{S1} = \frac{(V_{O1}+V_{F1})\times N_P \times (\frac{1}{f_{(min)}} - t_{on(max)} - t_q)}{V_{DC(min)}\times t_{on(max)}}$$

$$= \frac{(135+1)\times 59 \times (\frac{1}{29.6\times10^3} - 22.13\times10^{-6} - 2.5\times10^{-6})}{108\times 22.13\times10^{-6}} = 30.73 \cong 31 \quad [\text{Turn}]$$

The number of turns in the secondary coil is therefore $N_{S1}=31$.

⚠ Calculation assumes t_q =2.5μs.

5.3.5 Verification of Resonance Time (t_q)

The calculation above assumes a resonance period (t_q) of 2.5μs.
This calculation verifies the effectiveness of this value in terms of L_P and the resonance condenser C_q (C108) as previously calculated.

$$t_q = \frac{2\pi\sqrt{L_P \times C_g}}{2} = \frac{2\pi\sqrt{0.65\times10^{-3}\times1000\times10^{-12}}}{2} = 2.53 \quad [\text{μs}]$$

Conditions are therefore satisfied.
Note that the calculation assumes a resonance condenser C_q of 1000pF.

⚠ If the calculated value differs, change t_q and recalculate.

5.3.6 Calculation of Number of Turns in Secondary Coils (N_{S2}, N_{S3})

The numbers of turns N_{S2} and N_{S3} in the secondary coils are calculated using equation 14 in 5.2.2.

$$N_{S2} = N_{S1}\times\frac{V_{O2}+V_{F2}}{V_{O1}+V_{F1}} = 31\times\frac{35+1}{135+1} = 8.20 \cong 8 \quad [\text{Turn}]$$

$$N_{S3} = N_{S1}\times\frac{V_{O3}+V_{F3}}{V_{O1}+V_{F1}} = 31\times\frac{16+0.6}{135+1} = 3.78 \cong 4 \quad [\text{Turn}]$$

The numbers of turns in the secondary coils are $N_{S2}=8$ and $N_{S3}=4$.

5.3.7 Calculation of Number of Turns in Control Coil (N_C)

A value of between 15V and 17V is optimum for V_{CC}.
This design assumes V_{CC}=16V, and the number of turns in the control coil is calculated using equation 15 in 5.2.2.

$$N_C = N_{S1}\times\frac{V_{NC}+V_{FNC}}{V_{O1}+V_{F1}} = 31\times\frac{16+1}{135+1} = 3.88 \cong 4 \quad [\text{Turn}]$$

⚠ For ease of handling, a 0.2mm dia. wire is recommended for the control coil.

5.3.8 Calculation of Wire Size for Primary Coil (NP)

Coil size is calculated using the rated output power.
Cross-sectional area of the primary coil is calculated using equation 16 in 5.2.2.
With current density（α）set at 6A/mm^2,

$$A_{NP} = \frac{2 \times \sqrt{D} \times P_O}{\alpha \times \sqrt{3} \times \eta \times V_{DC(min)} \times t_{on(max)} \times f_{(min)}}$$

$$= \frac{2 \times \sqrt{0.655} \times 81.2}{6 \times \sqrt{3} \times 0.85 \times 108 \times 22.13 \times 10^{-6} \times 29.6 \times 10^3} = 0.210 \quad [\text{mm}^2]$$

A diameter of 0.50mm is therefore appropriate for the wire size of the primary coil.

⚠️ Adjust current density in accordance with conditions of use and structure of the transformer.

5.3.9 Calculation of Wire Size for Secondary Coils (NS1, NS2, NS3)

Cross-sectional area of the secondary coil is calculated in the same manner as in 5.3.8 using equation 17 in 5.2.2.
toff(max) is first calculated using equation 5 in 5.2.2.

$$t_{off(max)} = \frac{N_{S1} \times V_{DC(min)} \times t_{ON(max)}}{N_P \times (V_{O1} + V_{F1})} + t_q = \frac{31 \times 108 \times 22.13 \times 10^{-6}}{59 \times (135 + 1)} + 2.5 \times 10^{-6} = 11.73 \quad [\mu s]$$

$$A_{NS1} = \frac{2 \times \sqrt{1 - D - (t_q \times f_{(min)})} \times I_{O1}}{\alpha \times \sqrt{3} \times (t_{off(max)} - t_q) \times f_{(min)}} = \frac{2 \times \sqrt{1 - 0.655 - (2.5 \times 10^{-6} \times 29.6 \times 10^3)} \times 0.45}{6 \times \sqrt{3} \times (11.73 \times 10^{-6} - 2.5 \times 10^{-6}) \times 29.6 \times 10^3} = 0.165 \quad [\text{mm}^2]$$

$$A_{NS2} = \frac{2 \times \sqrt{1 - D - (t_q \times f_{(min)})} \times I_{O2}}{\alpha \times \sqrt{3} \times (t_{off(max)} - t_q) \times f_{(min)}} = \frac{2 \times \sqrt{1 - 0.655 - (2.5 \times 10^{-6} \times 29.6 \times 10^3)} \times 0.40}{6 \times \sqrt{3} \times (11.73 \times 10^{-6} - 2.5 \times 10^{-6}) \times 29.6 \times 10^3} = 0.146 \quad [\text{mm}^2]$$
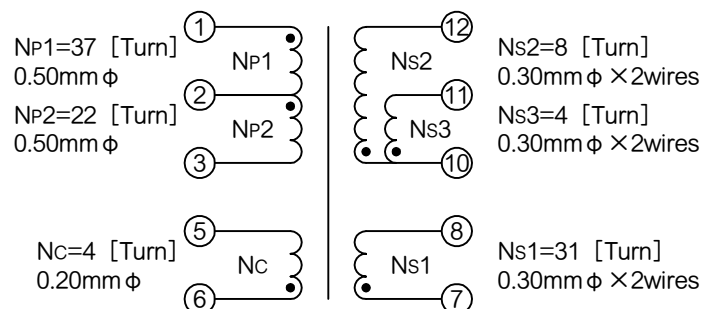
$$A_{NS3} = \frac{2 \times \sqrt{1 - D - (t_q \times f_{(min)})} \times I_{O3}}{\alpha \times \sqrt{3} \times (t_{off(max)} - t_q) \times f_{(min)}} = \frac{2 \times \sqrt{1 - 0.655 - (2.5 \times 10^{-6} \times 29.6 \times 10^3)} \times 0.40}{6 \times \sqrt{3} \times (11.73 \times 10^{-6} - 2.5 \times 10^{-6}) \times 29.6 \times 10^3} = 0.146 \quad [\text{mm}^2]$$

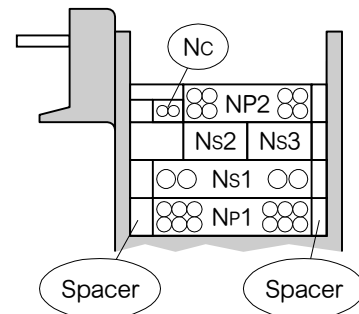The wire sizes for the secondary coils are therefore as follows.
NS1: 0.32mm dia. x 2 wires
NS2: 0.29mm dia. x 2 wires
NS3: 0.29mm dia. x 2 wires

NP1=37 [Turn]
0.50mmφ
NP2=22 [Turn]
0.50mmφ

NS2=8 [Turn]
0.30mmφ ×2wires
NS3=4 [Turn]
0.30mmφ ×2wires

NC=4 [Turn]
0.20mmφ

NS1=31 [Turn]
0.30mmφ ×2wires

Primary inductance (LP): 0.65mH (between transformer pins ① and ③)
Gap Ig: 0.87mm

The structure of the transformer requires that all turns in coil NS1 be in a single layer.

Fig.5.1 Transformer Specifications and Coil Structure

5.4.1 Values of Constants for MR2900 Peripheral Components (see 4. Standard Circuit on P12)

Component	Constant
C107	This is the power supply voltage rectification condenser. If this value is small operation at start-up readily becomes intermittent, and if it is too large start-up time becomes excessive. A value of between 47μF and 100μF is appropriate.
C108	This condenser determines the resonance frequency. Select the value on the basis of noise and efficiency etc. A value of between 820pF and 2200pF is appropriate for autosensing power supplies of between 75W and 150W capacity.
C109	This condenser is incorporated to deal with noise at pin 2. A value of approximately 4700pF is appropriate. Also beneficial in gain phase adjustment, however frequency response deteriorates if the value is too large.
C111	This is the partial resonance adjustment condenser. Adjust so that turn-on occurs at the resonance trough. Turn-on occurs earlier if this value is small, and later if it is large. A value of between 10pF and 33pF is appropriate.
R102	This is the current limiting damper resistor for C108. A value up to a few ohms is appropriate. Select the value on the basis of noise and efficiency etc.
R103	This is the over-current detection resistor. It determines the droop point. Calculate the resistance value as follows. [0.60 (over-current threshold voltage) / Droop point collector current at minimum input]
R104	Adjust on the basis of droop characteristics. Set to a value slightly higher than the droop point set with R103. A value of a few tens of kohms is appropriate.
R105	This resistor compensates for droop due to input voltage. Adjust on the basis of droop characteristics. A value of approximately 50kohms is appropriate.
R106	This resistor limits current at the Z/C pin. A value of approximately 20kohms is appropriate.
D102	This corresponds to the body diode for the main switching device (ultra high-speed IGBT). Select a high-speed diode in the 900V, 1A class.
D106	This is a Zener diode to compensate for droop due to input voltage. Select a diode for a Zener voltage at least equal to that found with the following equation. Zener voltage $=1.3 \times 150 \times \dfrac{N_C}{N_P}$ (assume an initial compensation voltage of 150V)

R105 and D106 are additional components for autosensing input specifications.

$T_{j(max)}$ for the MR Series is 150°C.

As operation of the MR Series is accompanied by an increase in temperature associated with power losses, it is necessary to consider the type of heat sink to be used. While a design which ensures that $T_{j(max)}$ is not exceeded is of absolute importance, the overheat protection function (T_{SD}=150°C (typical)) must be also considered in any design. The extent to which T_j is derated in a design is therefore extremely important in improving reliability.

6.1 Junction Temperature and Power Losses

The majority of power losses during operation of the MR Series are associated with the internal MOSFET.
If the majority of power losses are considered as ON losses, they may be expressed by the following equation.

$$P_D = V_{DS} \times I_D$$

The temperature increase ($\triangle T_j$) due to power losses (P_D) is expressed as,

$$\triangle T_j + T_a \leqq T_{j(max)}$$

and if T_{SD}=150°C (typical) and $T_{SD(min)}$=120°C are assumed, P_D is limited so that the following equation is satisfied.

$$\triangle T_j + T_a \leqq T_{SD(min)}$$

6.2 Junction Temperature and Thermal Resistance

T_j may be calculated as follows using the thermal resistance θ_{ja}.

$$T_j = (P_D \times \theta_{ja}) + T_a$$

θ_{ja} is the thermal resistance in the vicinity of the junction, and is expressed as follows.

$$\theta_{ja} = \theta_{jc} + \theta_{cf} + \theta_{fa}$$

	Abbreviation	Unit
Thermal resistance between junction and vicinity.	θ_{ja}	°C/W
Thermal resistance between junction and case.	θ_{jc}	°C/W
Thermal resistance between case and fins (contact thermal resistance).	θ_{cf}	°C/W
Thermal resistance between case and fins (contact thermal resistance).	θ_{fa}	°C/W

6.3 Cautions for Cooling Design

Thermal shutdown (TSD) is a protective function which stops and latches operation at 150°C in the event of abnormal heating of the MR1520. Circuit design therefore requires a cooling design in which temperature has been sufficiently derated.
Shindengen recommends that cooling design be such that case temperature does not exceed 100°C.