

**Flyback AC-DC Power Supply
Basic Simulation Circuit
Reference Guide**

RD035-RGUIDE-02

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

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1. Introduction

Most of the internal circuits in information and communication equipment, home appliances, and other electrical devices work on DC voltage. Since they cannot work on commercial power (AC voltage) directly, it is necessary to convert AC voltage to DC voltage. An AC-DC power supply is used for this purpose. In some cases, an external AC-DC power supply is installed to an actual applications. In other cases, it is embedded in an actual applications and therefore invisible from outside.

AC-DC power supplies have basically two categories: transformer-based AC-DC power supplies and switched-mode AC-DC power supplies. A transformer-based AC-DC power supply works stepping down the AC voltage through a transformer without changing its frequency, converting the negative portion of each AC cycle to positive voltage through a diode bridge (rectifier bridge), and smoothing out the DC voltage with a capacitor. A very large, heavy transformer that operates at the AC voltage frequency (50 or 60Hz) adds size and weight to the transformer-based AC-DC power supply. A switched-mode AC-DC power supply works rectifying AC voltage to DC voltage, switching the DC voltage at a frequency around 10kHz to 100kHz (much higher than the commercial power frequency), and passing it through a transformer to change the output voltage. The final output DC voltage is controlled by the on/off periods of switching devices. Power transmission at a high frequency allows the use of a small, lightweight transformer, making it possible to reduce the size and weight of an AC-DC power supply. So switched-mode AC-DC power supplies are commonly used nowadays.

Figure 1.1 shows typical block diagram of a switched-mode AC-DC power supply, which consists of four blocks: 1) input filter, 2) rectifier bridge, 3) DC-DC converter, and 4) feedback circuit. The function of each of these blocks is briefly explained below:

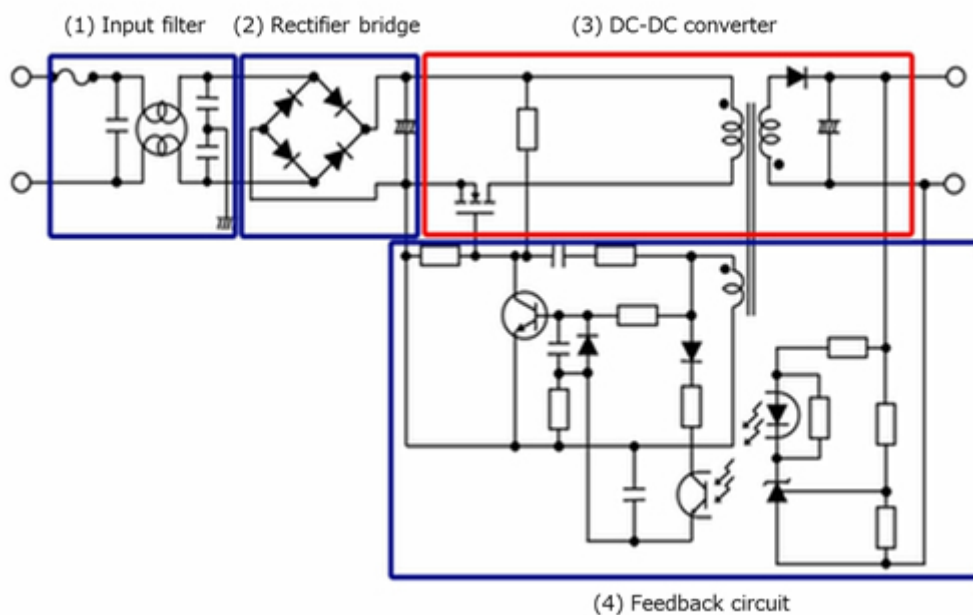


Figure 1.1 Block diagram of a switched-mode AC-DC power supply

(1) Input filter

The input filter prevents noise generated by the switched-mode AC-DC power supply to the commercial power line.

(2) Rectifier bridge

The rectifier bridge rectifies the input AC voltage into a first DC voltage and passes it to the DC-DC converter. The configuration consisting of a rectifier bridge and a capacitor as shown in Figure 1.1 degrades the power factor. In recent years, a power factor correction (PFC) circuit is typically inserted in the rectifier bridge to prevent power factor degradation. Toshiba also offers a basic simulation circuit of a PFC power supply together with a reference design:

For a basic simulation circuit of a PFC power supply →

[Click Here](#)

(3) DC-DC converter

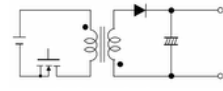
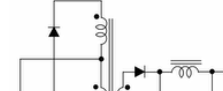
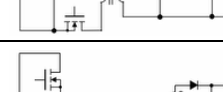
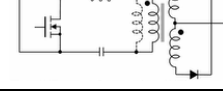
The DC-DC converter converts the rectified voltage to an intermediate DC voltage.

(4) Feedback circuit

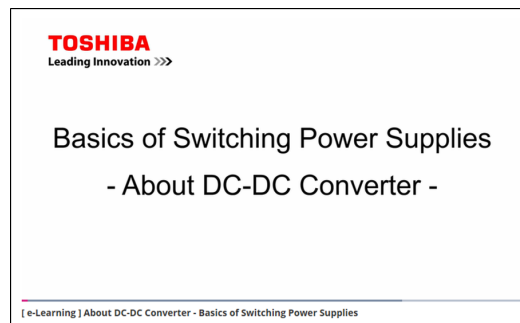
The on/off periods of the switching devices are controlled to generate a desired output voltage.

A switched-mode AC-DC power supply rectifies the AC input voltage into a first DC voltage and converts it to a desired DC voltage through a DC-DC converter. Many topologies exist for the implementation of a DC-DC converter. Table 1.1 shows the most common topologies and their characteristics.

Table 1.1 Commonly used DC-DC converter topologies and their characteristics

| Topology | Power Level | Advantage | Disadvantage |
|---|---------------|---|--|
|  | <120W | <ul style="list-style-type: none"> Small part count | <ul style="list-style-type: none"> Decrease in efficiency at high power Large transformer |
|  | 100W to 500W | <ul style="list-style-type: none"> Higher efficiency than a flyback circuit | <ul style="list-style-type: none"> Requires a transformer reset circuit |
|  | 100W to 1.6kW | <ul style="list-style-type: none"> High efficiency Low noise | <ul style="list-style-type: none"> Requires a custom-designed transformer Difficult to control |
|  | >1kW | <ul style="list-style-type: none"> High efficiency Capable of increasing the power capacity | <ul style="list-style-type: none"> Large part count Difficult to control |

A [video](#) describing the basic operation of a DC-DC converter is available for viewing on Toshiba's website.



The flyback DC-DC converter has the merit of realizing simple circuit, however the flyback topology has a lower efficiency and requires a larger transformer at high output power than other topologies. Therefore, flyback DC-DC converters suit power supplies with a relatively small power capacity. A basic simulation circuit of a flyback DC-DC converter for a switched-mode AC-DC power supply (RD035-SPIICE-02) is available for download on Toshiba's website, which will help you understand its operation.

The Reference Guide provides an overview of this simulation circuit and shows how to simulate. OrCAD Capture and PSpice A/D from Cadence are necessary to simulate this circuit. Both the simulation circuit and the Reference Guide are based on OrCAD 17.2.

2. Overview of the AC-DC flyback power supply

The basic simulation circuit (RD035-SPICE-02) is a 65W AC-DC power supply with a DC-DC flyback converter. The assumption is that the input AC voltage is converted to DC voltage through a rectifier bridge and a PFC circuit before the DC voltage is applied to the DC-DC flyback converter.

2.1. Power supply specifications

The specifications of the flyback AC-DC power supply are as follows:

- Input voltage = 380V
- Output voltage: 16V
- Output current: 0 to 4.1A
- Operating frequency: 100kHz
- Flyback voltage: 110V
- Primary-side peak current: 1A
- Transformer primary-winding setting: 5000 μ H
- Transformer secondary-winding setting: 110 μ H

2.2. Circuit configuration

Figure 2.1 shows the simulation circuit for OrCAD. It is a flyback AC-DC power supply, which mainly consists of a power supply section (flyback circuit) and a PWM controller. The secondary side of the transformer in the flyback circuit is synchronous rectifier circuit using MOSFET. The PWM controller is a general-purpose controller with a MOSFET gate driver, which was prepared to create this flyback AC-DC power supply. The flyback circuit uses the TK380A65Y and TPN1200APL as switching MOSFETs.

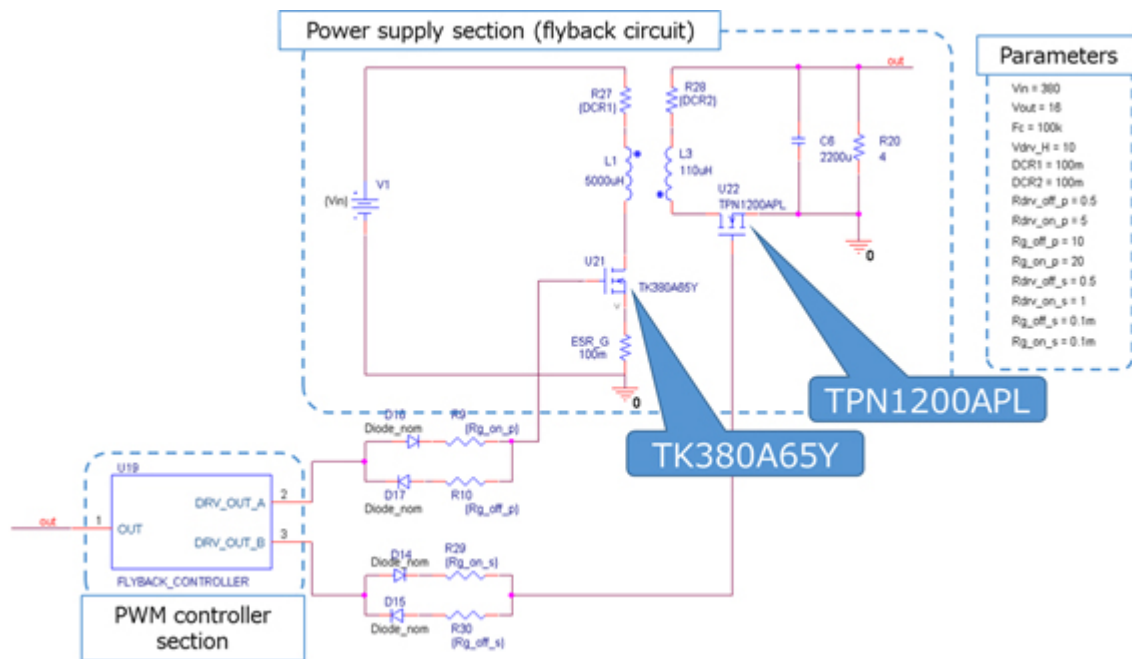


Figure 2.1 Simulation circuit of a 65W flyback AC-DC power supply

Selection of the primary-side MOSFET

The primary-side MOSFET (TK380A65Y with a V_{DSS} of 650V and an I_D of 9.7A) was selected, taking the following into consideration:

1. Withstand voltage

Since the input voltage is 380V, the flyback voltage is 110V, and the voltage across the primary winding in the steady state is 490V, a MOSFET with a withstand voltage of 650V or higher must be selected for the primary-side MOSFET.

2. Current rating

The flyback AC-DC power supply has the maximum input current at the maximum output power. If the flyback AC-DC power supply has a conversion efficiency of 85% at the maximum output power of 65W, then the maximum input current is calculated to be 0.2Arms. The design value of the peak current of the primary winding is 1A. So a MOSFET with a peak current rating of 2A or higher must be selected for the primary-side MOSFET.

Selection of the secondary-side MOSFET

The secondary-side MOSFET (TPN1200APL with a V_{DSS} of 100V and an I_D of 40A) was selected, taking the following into consideration:

1. Withstand voltage

The voltage across the secondary winding (V_s) in the steady state can be calculated as follows:

$$V_s = \frac{V_{out}}{V_{flyback}} \times V_{in} + V_{out}$$

where, the input voltage (V_{in}) is 380V, the flyback voltage ($V_{flyback}$) is 110V, and the output voltage (V_{out}) is 16V. So V_s is calculated to be 71.3V. Thus a MOSFET with a withstand voltage of 100V or higher was selected for the secondary-side MOSFET.

2. Current rating

The flyback AC-DC power supply has the maximum output current at the maximum output power. Since the maximum output current is 4.1Arms at the maximum output power of 65W, a MOSFET with a current rating of 6A or higher was selected for the secondary-side MOSFET.

Selection of a transformer

The following paragraphs explain how to select a transformer. The inductance of the transformer to be used in the simulation circuit can be calculated from the following power supply parameters:

- Input voltage: V_{in} (V)
- Output voltage: V_{out} (V)
- Flyback voltage: $V_{flyback}$ (V)
- Switching frequency: F_C (Hz)
- Power conversion efficiency: η (%)
- Output current: I_{out} (A)

The inductance of the primary winding of the transformer (L_p) can be calculated as follows:

$$L_p = \frac{V_{in}^2 \times \eta \times 0.01 \times \left(\frac{V_{flyback}}{V_{in} + V_{flyback}} \right)^2}{2 \times I_{out} \times V_{out} \times F_c}$$

The ratio (n) of the number of turns of the primary winding (N_p) to the number of turns of the secondary winding (N_s) can be calculated as follows:

$$n = \frac{N_p}{N_s} = \frac{V_{flyback}}{V_{out} + V_{flyback}}$$

The inductance of the secondary winding (L_s) can be calculated as follows from the inductance of the primary winding (L_p) and the turns ratio (n):

$$L_s = L_p \times \frac{1}{n^2}$$

From the power supply specifications of this simulation circuit model, it has the input voltage (V_{in}) is 380V, the output voltage (V_{out}) is 16V, the flyback voltage ($V_{flyback}$) is 110V, and the switching frequency (F_c) is 100kHz, and the power conversion efficiency (η) is 85%. Assuming that the flyback AC-DC converter operates in continuous-current mode at 10% load, it is necessary to calculate inductance at an output current (I_{out}) of 0.4A and set the inductance to a value higher than that. From the above equations, the inductance of the primary winding (L_p) is calculated to be 4.7mH, the turns ratio (n) to be 6.7, and the inductance of the secondary winding (L_s) to be 106 μ H. So we set L_p to 5.0mH, n to 7, and L_s to 110 μ H in the simulation model.

In actual design, the inductance values vary because of DC bias characteristics. Select a transformer that exhibits inductance values greater than the above results even when the inductance values decrease because of DC bias characteristics.

3. Simulation results

This section shows the simulation waveforms at the points (1) to (3) shown in Figure 3.1.

- (1) Basic operation of the flyback AC-DC power supply (current and voltage of the primary and secondary windings related to the flyback operation)
- (2) Synchronous rectification on the secondary side (gate voltage, drain-source voltage, and drain current of the MOSFETs related to synchronous rectification)
- (3) Output voltage and current from the flyback AC-DC power supply

The simulation circuit model also allows you to view other waveforms. See Section 5 for how to view waveforms.

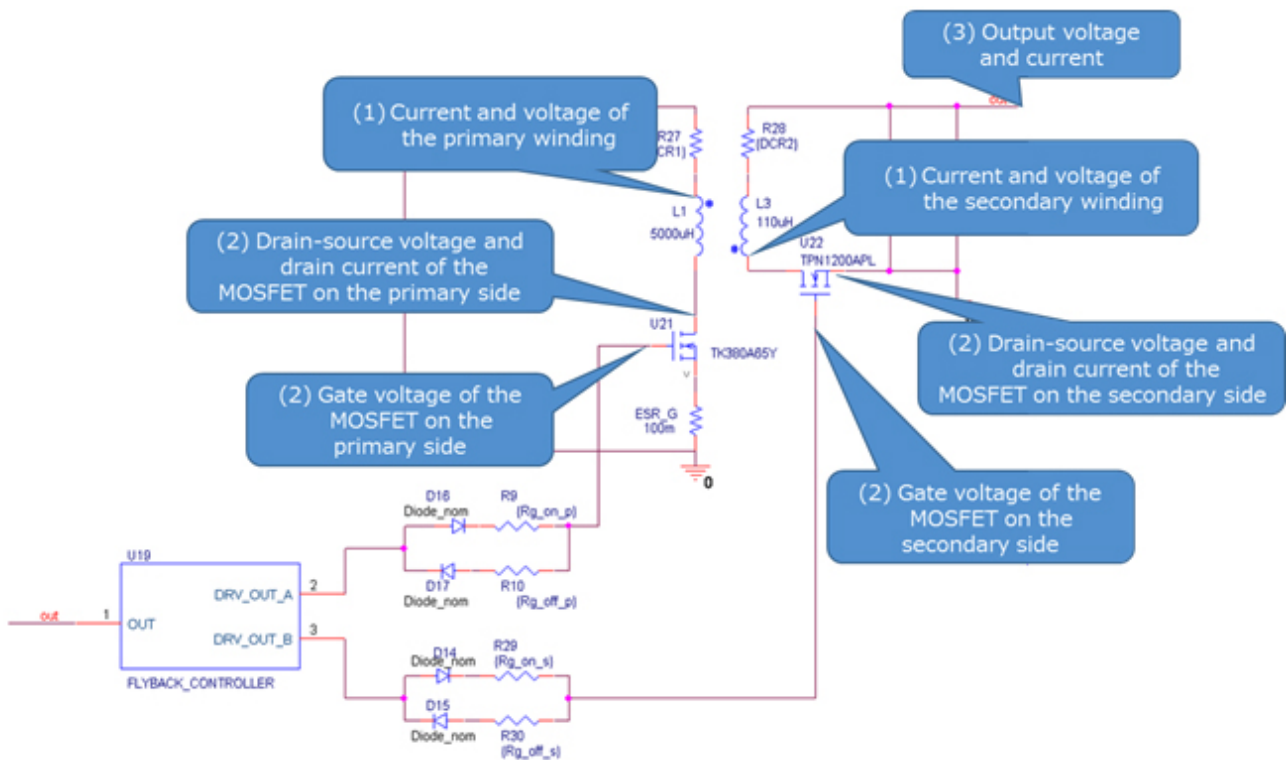


Figure 3.1 Current and voltage measurement points during simulation

(1) Basic operation of flyback AC-DC power supply

The following paragraphs explain the basic operation of the flyback AC-DC power supply, referring to the DC-DC converter shown in Figure 3.2.

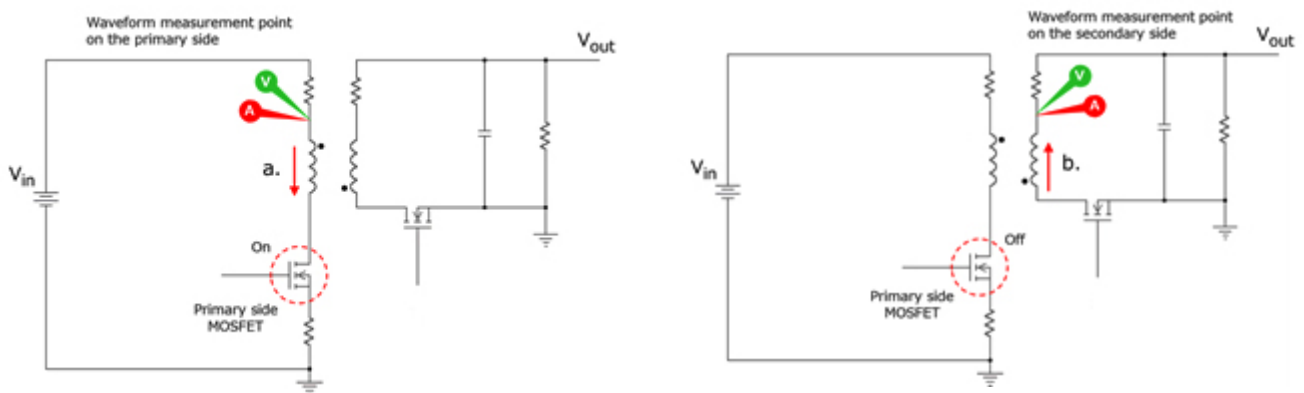


Figure 3.2 Points of measurement of flyback operation

a. The primary-side MOSFET turns on.

Current flows through the primary winding in the direction shown by the arrow.

At this time, the primary-winding voltage becomes equal to the input voltage (V_{in}). The voltage that appears across the secondary winding depends on the turns ratio: $N_s/N_p \times V_{in}$. If that the polarity marking on the secondary side indicates the positive terminal, then the voltage at the measurement point shown in Figure 3.2 is $-(N_s/N_p \times V_{in})$. The sum of V_{out} and $(N_s/N_p \times V_{in})$ is applied to the devices on the secondary side. So the devices on the secondary side must have a withstand voltage greater than $V_{out} + (N_s/N_p \times V_{in})$.

b. The primary-side MOSFET turns off.

The energy stored in the transformer is discharged to the output through the secondary winding.

At this time, the voltage across the secondary winding is equal to the output voltage (V_{out}). If that the polarity marking on the primary side indicates the negative terminal, then the voltage that appears across the primary winding is calculated as $N_p/N_s \times V_{out}$, depending on the turns ratio. This voltage is called the flyback voltage ($V_{flyback}$). The sum of V_{in} and $V_{flyback}$ is applied to the devices on the primary side. Therefore, the devices on the primary side must have a withstand voltage greater than $(V_{in} + V_{flyback})$.

Steps a and b are repeated.

Figure 3.3 shows the voltage and current waveforms of the primary and secondary windings. As shown in Figure 3.3, voltage is alternately applied across the primary and secondary windings, and current flows through each winding while voltage is applied.

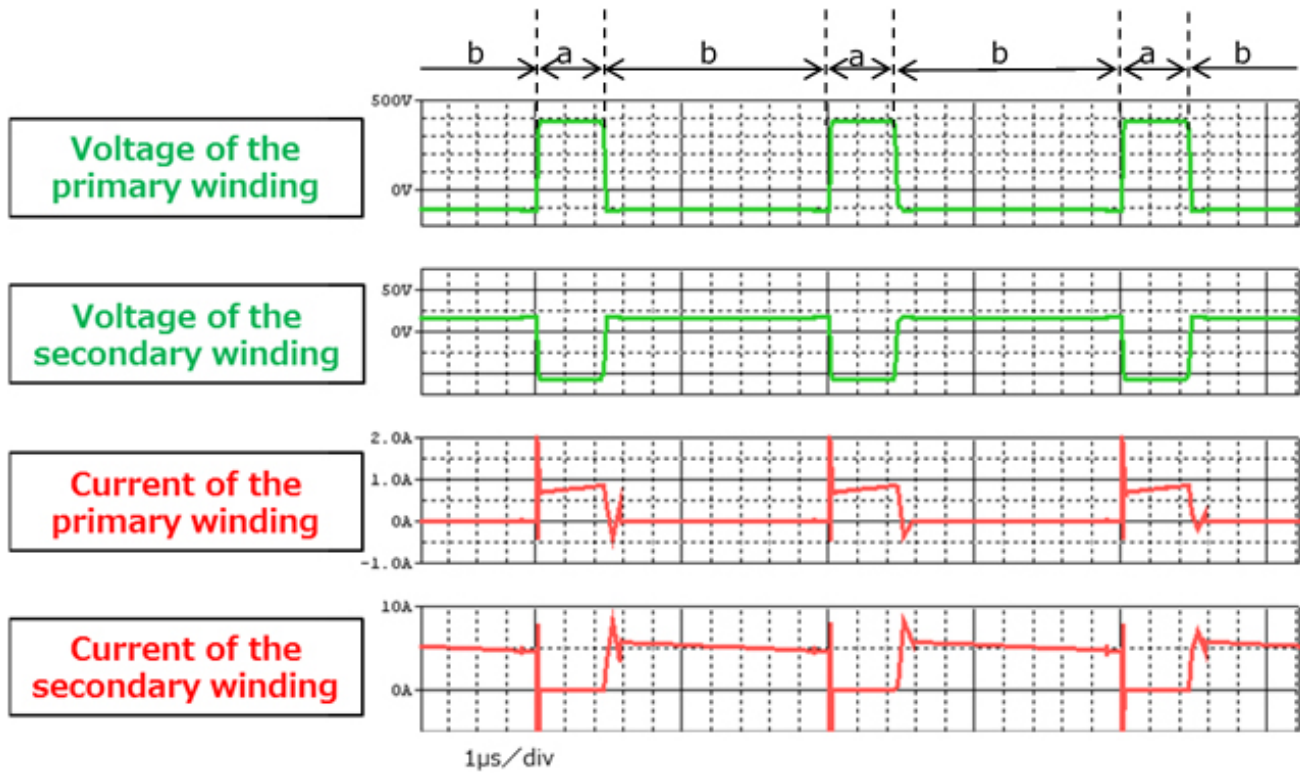


Figure 3.3 Voltage and current waveforms of the primary and secondary windings

(2) Synchronous rectification on the secondary side

The secondary side of the simulation circuit is a synchronous rectification circuit, in which a MOSFET is used instead of diodes. When the MOSFET on the primary side turns off, the transformer reverses the polarity of the secondary-winding voltage, releasing the charged energy to the output. This turns on the MOSFET on the secondary side, allowing current to flow through it. While current is flowing in the circuit on the secondary side of the transformer, a diode rectifier causes a loss proportional to the diode forward voltage, whereas the MOSFET rectifier causes a loss because of the MOSFET on-resistance. Since a voltage drop due to the MOSFET on-resistance is generally lower than the diode forward voltage, a MOSFET synchronous rectifier incurs less loss than a diode rectifier. However, a MOSFET synchronous rectifier requires a dedicated drive circuit to control the MOSFET on/off timing, which incurs a loss due to MOSFET drive.

Figure 3.4 shows a DC-DC converter. The following paragraphs describe the basic operation of synchronous rectification using this circuit.

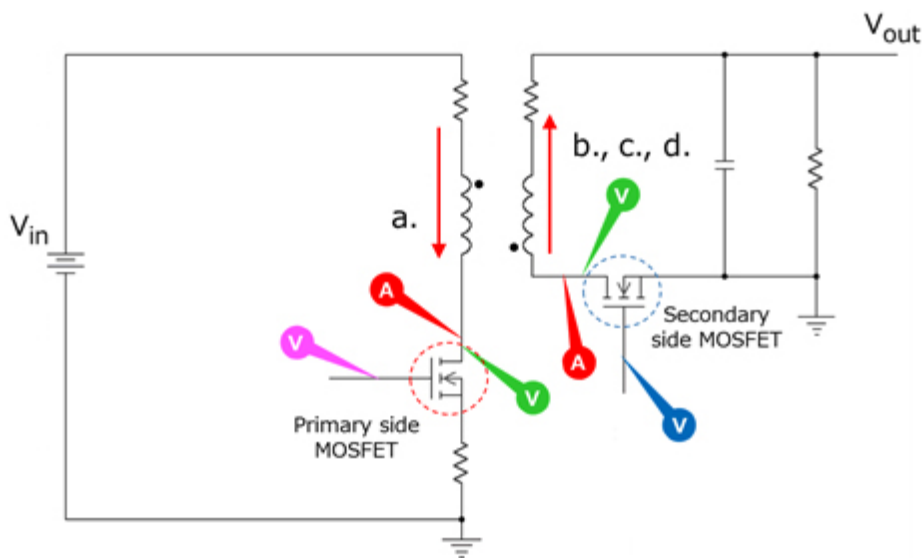


Figure 3.4 Points of measurement during synchronous rectification

- a. The primary-side MOSFET turns on, and the secondary-side MOSFET turns off.
As current flows through the primary winding, energy is charged in the transformer.
- b. The primary-side MOSFET turns off, and the secondary-side MOSFET remains off.
The polarity of the voltage across the secondary winding reverses. This induces a current in the secondary winding, causing the stored energy to be discharged. Since the secondary-side MOSFET is in the off state, this current flows through the parasitic diode of the MOSFET.
- c. The primary-side MOSFET remains off, and the secondary-side MOSFET turns on.
The polarity of the voltage across the secondary winding reverses. Then, the secondary-side MOSFET turns on, allowing a current to flow through it.
- d. The primary-side MOSFET remains off, and the secondary-side MOSFET turns off.

The secondary-side MOSFET turns off before the primary-side MOSFET turns on. Since the transformer is still discharging the charged energy, the current on the secondary side flows through the parasitic diode of the MOSFET.

Steps a to d are repeated.

Figure 3.5 shows the gate voltage, drain-source voltage, and drain current of the primary- and secondary-side MOSFETs. As shown in Figure 3.5, these MOSFETs turn on and off alternately with dead-time periods (b and d) inserted (during which both MOSFETs are off).

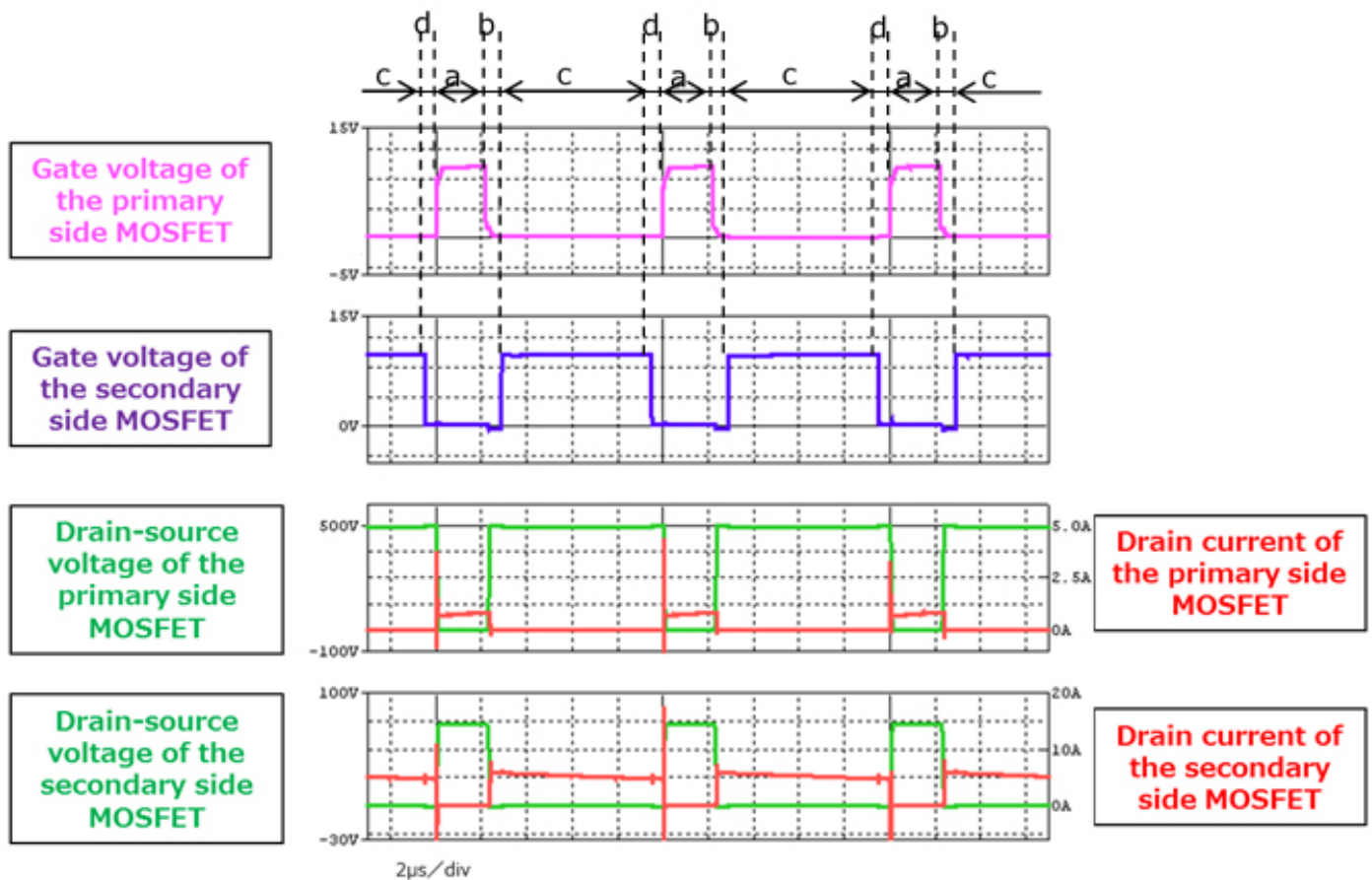


Figure 3.5 Gate voltage, drain-source voltage, drain current waveforms of the primary- and secondary-side MOSFETs

Figure 3.6 shows the gate voltage, drain-source voltage, and drain current of the secondary-side MOSFET during turn-on (b-to-c transition) and turn-off (c-to-d transition). The I_D waveform shows that a current flows during a period from the beginning of b (prior to turn-on) to the end of d (after turn-off). V_{DS} differs considerably between the periods of b and d during which current flows through the parasitic diode of the MOSFET and the period of c during which the MOSFET is in the on state. This indicates that the synchronous rectification circuit helps reduce power loss.

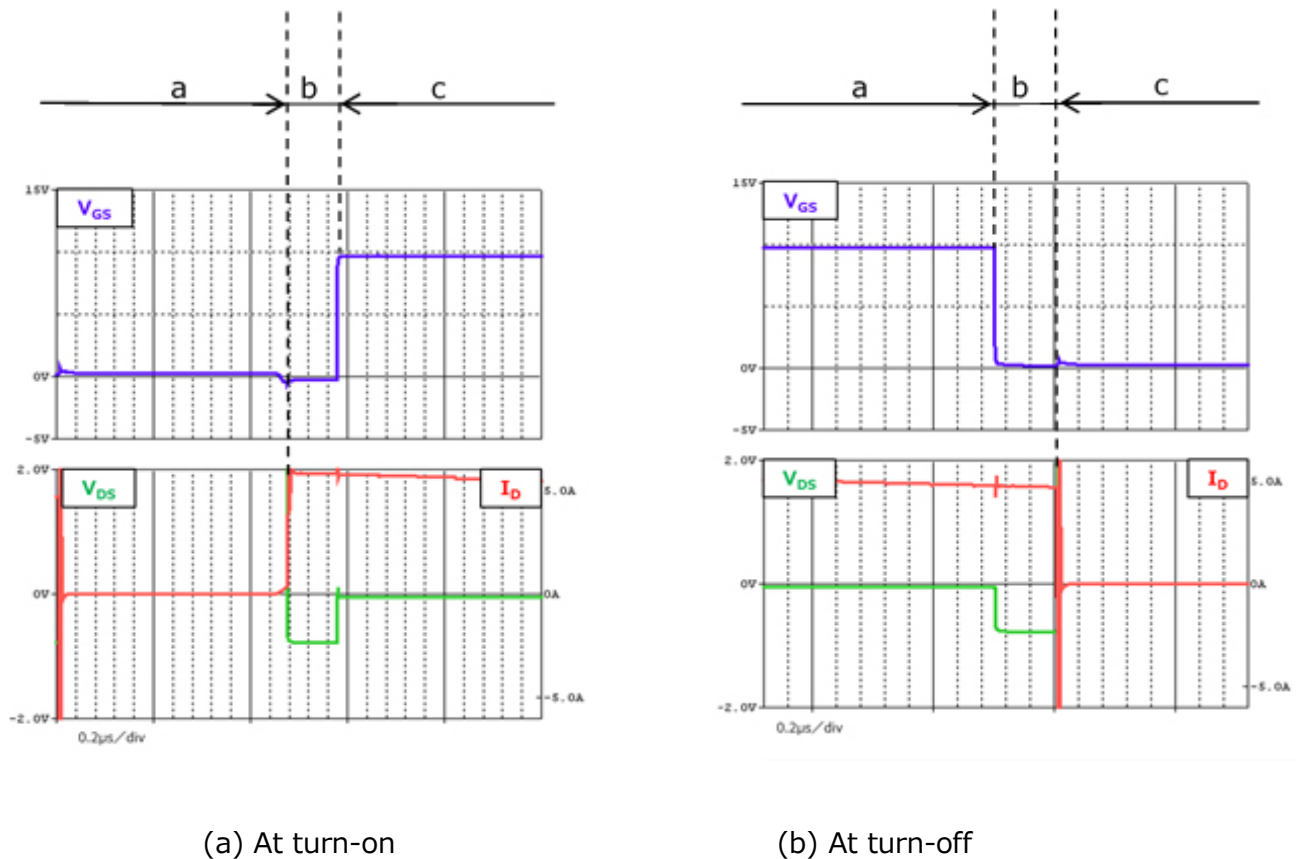


Figure 3.6 Gate voltage, drain-source voltage, and drain current waveforms of the secondary-side MOSFET

(3) Output voltage and current from the flyback AC-DC power supply

Figure 3.7 shows the output voltage and current waveforms of the flyback AC-DC power supply. As shown, the output voltage and current remain stable at the desired values.

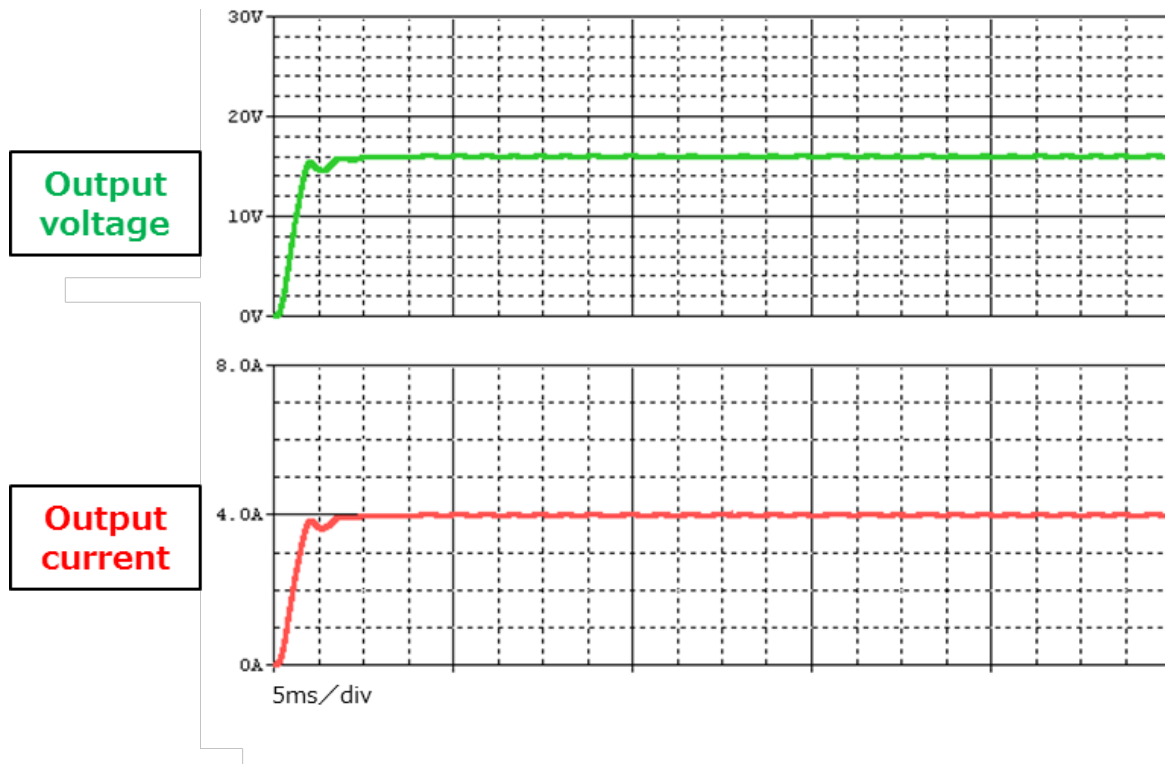


Figure 3.7 Output voltage and current waveforms

4. Product Overview

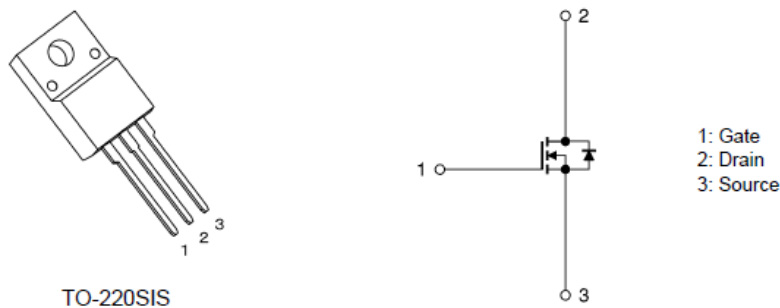
This section provides an overview of Toshiba’s devices used as PSpice models in the simulation circuit.

4.1. TK380A65Y

Characteristics

- $V_{DSS}=650V, I_D=9.7A$
- Low on-resistance due to the use of a super-junction DTMOS process: $R_{DS(ON)} = 0.29\Omega$ typical
- Optimized gate switching speed
- Easy-to-use enhanced-mode MOSFET: $V_{th} = 3$ to $4V$ ($V_{DS} = 10V, I_D = 0.36mA$)

External view and pin assignment

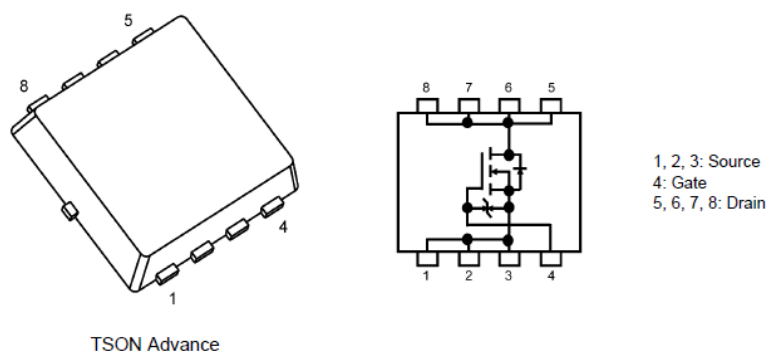


4.2. TPN1200APL

Characteristics

- $V_{DSS}=100V, I_D=40A$
- Fast switching
- Low input gate charge: $Q_{SW} = 7.5nC$ typical
- Low output charge: $Q_{OSS} = 24nC$ typical
- Low on-resistance: $R_{DS(ON)}= 9.8m\Omega$ typical (at $V_{GS} = 10V$)
- Low leakage current: $I_{DSS} = 10\mu A$ maximum (at $V_{DS}=100V$)
- Easy-to-use enhanced-mode MOSFET: $V_{th} = 1.5$ to $2.5V$ ($V_{DS} = 10V, I_D = 0.3mA$)

External view and pin assignment



3.3mm (W) × 3.3mm (L) × 0.85mm (H)

5. Using the simulation circuit

You can freely change various parameters with OrCAD Capture to verify the circuit operation according to the actual power supply specifications and evaluate how these parameters affect the circuit operation. This section shows how to set simulation parameters and verify the circuit operation.

Parameter settings

Table 5.1 shows the parameters you can set for the simulation circuit. Double-click a parameter name in the PARAMETERS section, then the Display Properties dialog box appears as shown in Figure 5.1. Change the value in the Value field.

Table 5.1 Parameters that can be modified in the Parameters section

| Parameter name | Unit | Description |
|----------------|----------|--|
| Vin | V | Input voltage |
| Vout | V | Output voltage |
| DCR1 | Ω | Parasitic resistance of the primary winding of the transformer |
| DCR2 | Ω | Parasitic resistance of the secondary winding of the transformer |
| Fc | Hz | Switching frequency |
| Rg_on_p | Ω | External turn-on gate resistor for the primary-side MOSFET |
| Rg_off_p | Ω | External turn-off gate resistor for the primary-side MOSFET |
| Rdrv_on_p | Ω | Internal resistance of the turn-on gate driver for the primary-side MOSFET |
| Rdrv_off_p | Ω | Internal resistance of the turn-off gate driver for the primary-side MOSFET |
| Rg_on_s | Ω | External turn-on gate resistor for the secondary-side MOSFET |
| Rg_off_s | Ω | External turn-off gate resistor for the secondary-side MOSFET |
| Rdrv_on_s | Ω | Internal resistance of the turn-on gate driver for the secondary-side MOSFET |
| Rdrv_off_s | Ω | Internal resistance of the turn-on gate driver for the secondary-side MOSFET |
| Vdrv_H | V | Supply voltage of the gate driver |

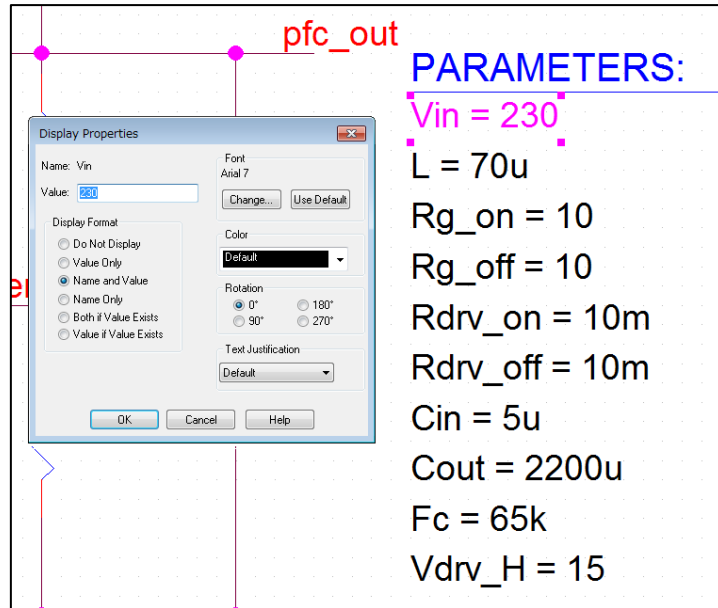


Figure 5.1 Display Properties dialog box

Setting analysis parameters

The following describes how to run a simulation on the simulation circuit.

1. From the menu bar of OrCAD Capture, select **PSpice - New Simulation Profile**. Then, the New Simulation dialog box shown in Figure 5.2 appears. Enter an arbitrary profile name and click **Create**.

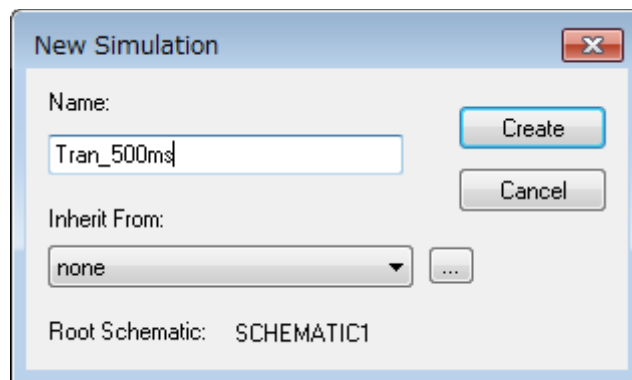


Figure 5.2 New Simulation dialog box

2. Then, the Simulation Settings dialog box shown in Figure 5.3 appears. In this dialog box, you can set parameters for various types of analysis. First, click the **Analysis** tab. Select **Time Domain (Transient)** from the **Analysis Type** drop-down list. Enter the simulation end time in the **Run To Time** field and the maximum step size in the **Maximum Step Size** field.

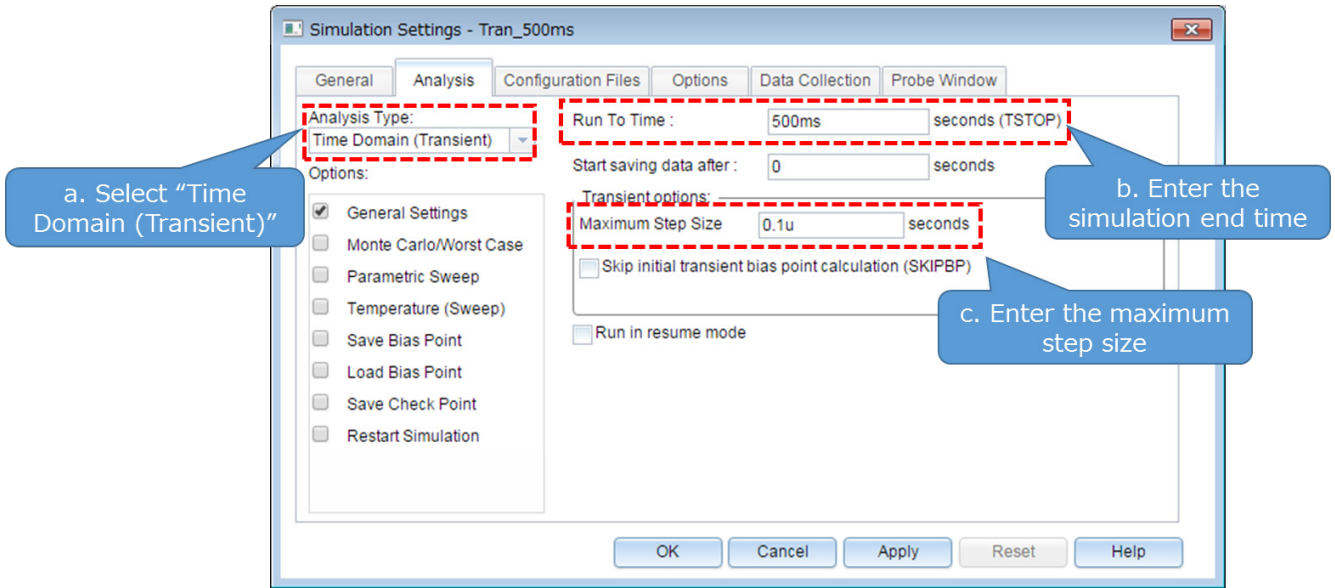


Figure 5.3 Simulation Settings - Analysis dialog box

3. Click the **Options** tab to choose analysis options. For the simulation of our model, it is recommended to check **Analog Simulation - Auto Converge - AutoConverge** as shown in Figure 5.4 to enable the automatic convergence feature.

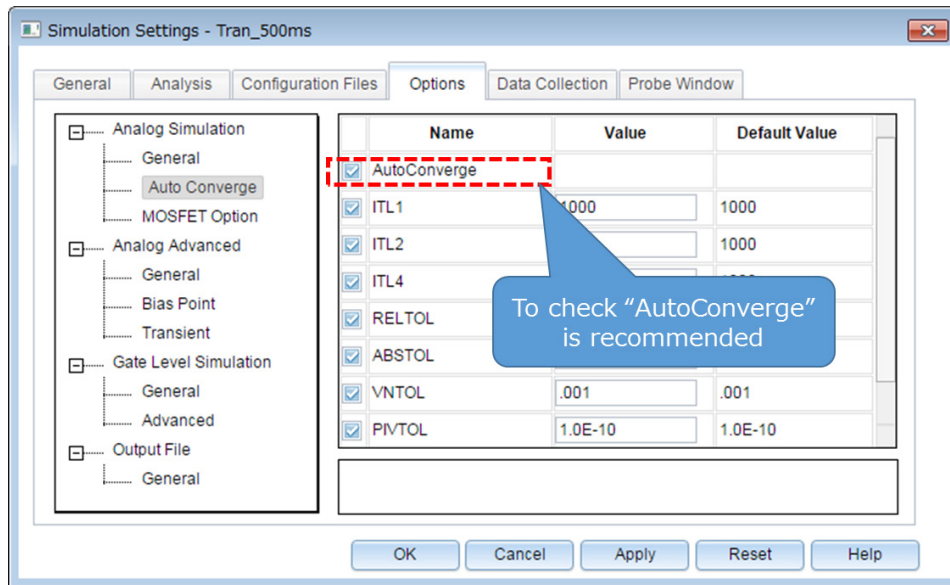


Figure 5.4 Simulation Settings - Options dialog box

4. Click **OK** to close the Simulation Settings dialog box.
5. To run a simulation, select **PSpice - Run** from the menu bar of OrCAD Capture. Then, PSpice A/D starts automatically and runs a simulation.

Viewing simulation results

The following describes how to view the simulation results. You can display the waveforms of the simulation results in two ways.

Method 1: Selecting traces

1. Right-click outside the graph area and select **Add Trace** as shown in Figure 5.5.
2. Then, the Add Traces dialog box shown in Figure 5.6 appears. Select traces to be added to a selected plot. To view a voltage waveform, select $V(\text{trace_name})$. To view a current waveform, select $I(\text{device_name})$. See Figure 5.6.
3. Click **OK**. Then, the selected waveform appears as shown in Figure 5.7.

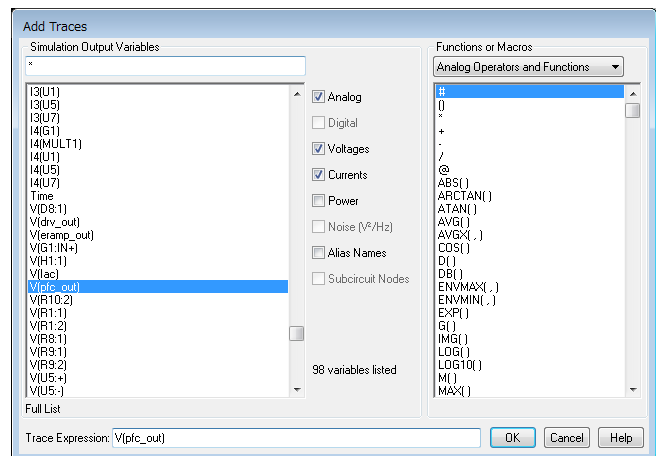
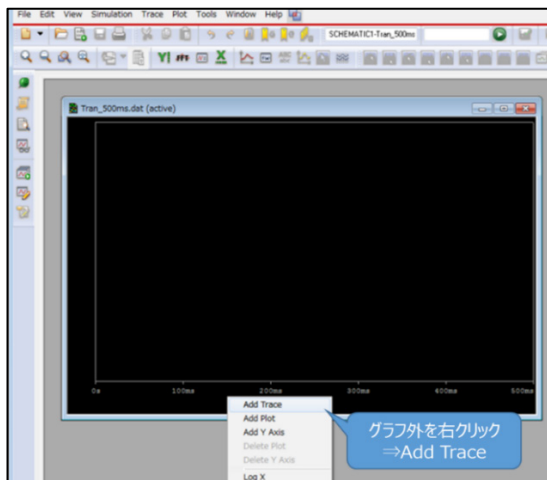


Figure 5.5 Graph window Figure 5.6 Add Traces dialog box

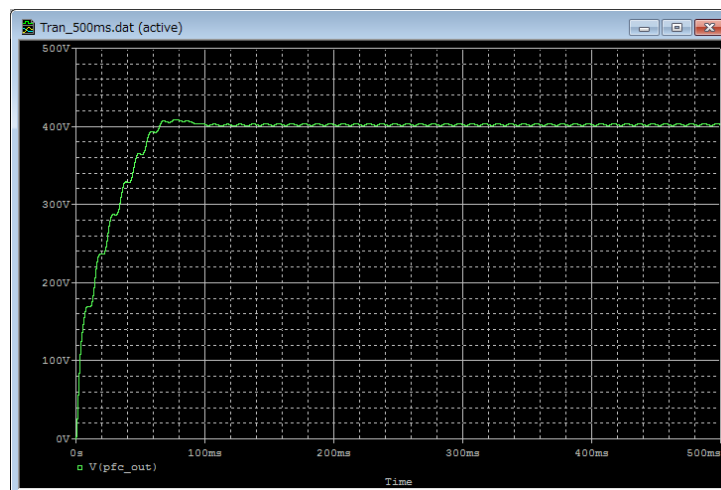


Figure 5.7 Simulation waveform view (Example: PFC output voltage waveform)

Method 2: Adding markers

1. From the menu bar of OrCAD Capture, select **PSpice - Markers** and then a type of marker as shown in Figure 5.8.
2. Place the selected marker on the desired node in the simulation circuit as shown in Figure 5.9.
3. Then, its waveform appears in the graph window of PSpice A/D as shown in Figure 5.10.

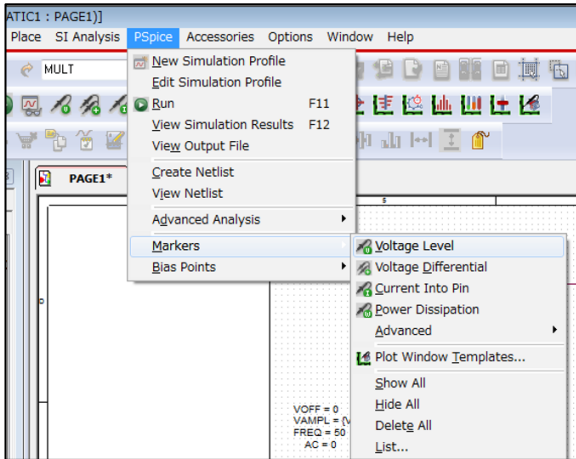


Figure 5.8 Selecting a marker type

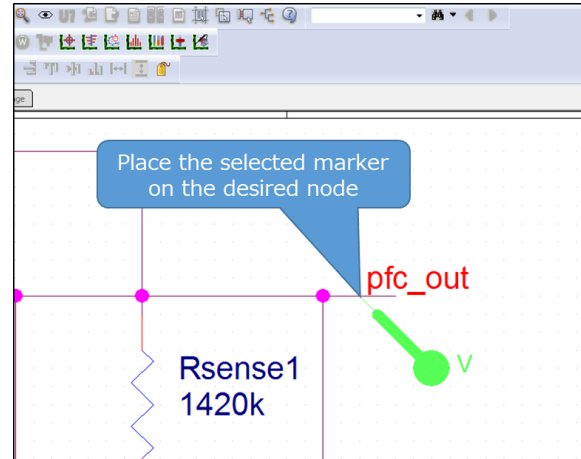


Figure 5.9 Placing a marker in the circuit

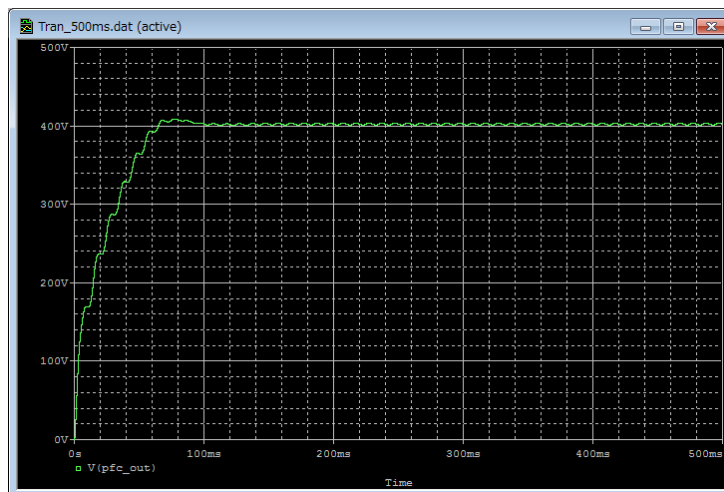


Figure 5.10 Simulation waveform view (Example: Output voltage waveform)

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