# Panasonic

# AN8014S

## Step-down, step-up, or inverting DC-DC converter control IC

### ■ Overview

The AN8014S is a single-channel PWM DC-DC converter control IC.

This IC can provide any one output type from among step-down, step-up and inverting output.

Allowing n-channel power MOSFET direct driving, the AN8014S is ideal for high-efficiency power supplies.

### ■ Features

- Wide operating supply voltage range (3.6 V to 34 V) (The voltage is limited within a range between 3.6 V and 17 V if it is connected to a step-down voltage circuit.)
- Totem pole output circuit: output peak current (±1 A)
- On-chip pulse-by-pulse overcurrent detection and protection circuit

    Threshold voltage $V_{CC} - 0.095$ V typical
- On-chip bootstrap circuit (allowing n-channel MOSFET direct driving.)
- On-chip under-voltage lock-out circuit (U.V.L.O.)
- On-chip on/off function (active-high control input, standby current of maximum 5 µA)
- On-chip timer latch short-circuit protection circuit
- Maximum oscillator frequency (500 kHz)

### ■ Applications

- DC-DC switching power supply

Unit: mm



SOP016-P-0225A

### ■ Block Diagram



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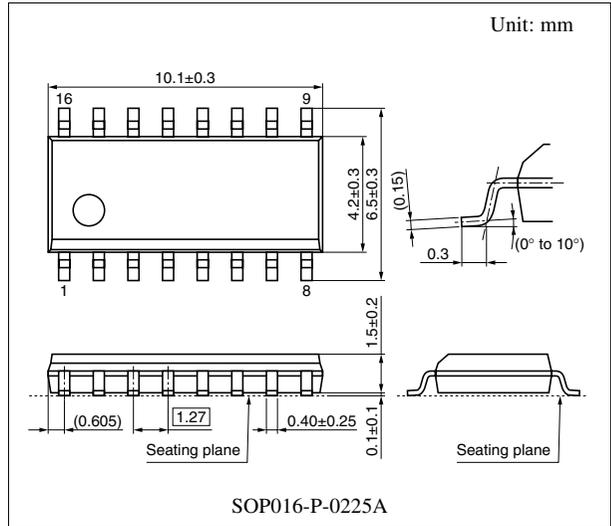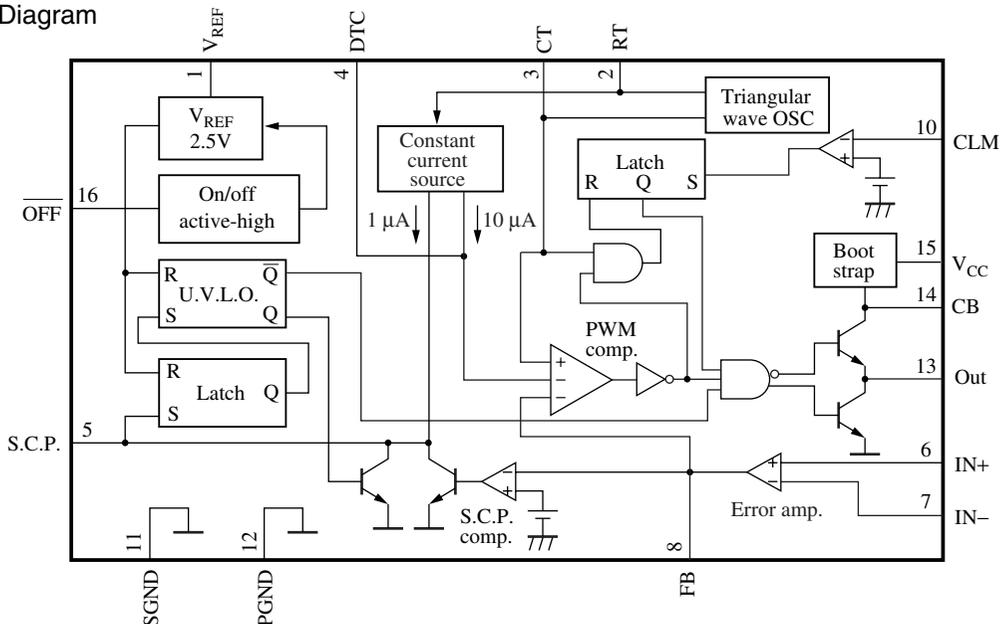
## ■ Pin Descriptions

| Pin No. | Description | Pin No. | Description |
|---|---|---|---|
| 1 | Internal reference output | 9 | Not connected |
| 2 | Oscillator timing resistor connection | 10 | Overcurrent protection input |
| 3 | Oscillator timing capacitor connection | 11 | Signal ground |
| 4 | Dead-time control | 12 | Output stage ground |
| 5 | Capacitance connection for short-circuit protection delay | 13 | Totem pole type output |
| | | 14 | Bootstrap output |
| 6 | Error amplifier noninverting input | 15 | Supply voltage |
| 7 | Error amplifier inverting input | 16 | On/off control |
| 8 | Error amplifier output | | |

## ■ Absolute Maximum Ratings

| Parameter | Symbol | Rating | Unit |
|---|---|---|---|
| Supply voltage | $V_{CC}$ | 35 | V |
| Supply current | $I_{CC}$ | — | mA |
| Power dissipation [2] | $P_D$ | 143 | mW |
| Operating ambient temperature [1] | $T_{opr}$ | −30 to +85 | °C |
| Storage temperature [1] | $T_{stg}$ | −40 to +125 | °C |
| On/off pin allowable application voltage | $V_{ON/OFF}$ | $V_{CC}$ | V |
| Error amplifier allowable input voltage | $V_I$ | − 0.3 to $V_{REF}$ | V |
| DTC pin allowable application voltage | $V_{DTC}$ | − 0.3 to $V_{REF}$ | V |
| Out pin allowable application voltage | $V_{OUT}$ | 35 | V |
| Out pin constant output current | $I_O$ | ±100 | mA |
| Out pin peak output current | $I_{O(Peak)}$ | ±1 000 | mA |
| CB pin allowable application voltage | $V_{CB}$ | 35 | V |
| CB pin constant output current | $I_{CB}$ | −100, 150 | mA |
| CB pin peak output current | $I_{CBP}$ | −500, 1 000 | mA |
| CLM pin allowable application voltage | $V_{CLM}$ | $V_{CC}$ | V |

Note) 1. *1: Except for the operating ambient temperature and storage temperature, all ratings are for $T_a = 25$°C.

　　　　*2: At $T_a = 85$°C

　　2. Do not apply external currents or voltages to any pins not specifically mentioned.

　　　For circuit currents, '+' denotes current flowing into the IC, and '−' denotes current flowing out of the IC.

## ■ Recommended Operating Range

| Parameter | Symbol | Range | | Unit |
|---|---|---|---|---|
| Supply voltage | $V_{CC}$ | Step-up circuit system | 3.6 to 34 | V |
| | | Step-down circuit system | 3.6 to 17 | |

■ Electrical Characteristics at $V_{CC} = 12$ V, $T_a = 25°C$

| Parameter | Symbol | Conditions | Min | Typ | Max | Unit |
|-----------|--------|-----------|-----|-----|-----|------|
| **Reference voltage block** | | | | | | |
| Output voltage | $V_{REF}$ | $I_{REF} = -1$ mA | 2.522 | 2.6 | 2.678 | V |
| Line regulation with input fluctuation | Line | $V_{CC} = 3.6$ V to 34 V | — | 16 | 25 | mV |
| Load regulation | Load | $I_{REF} = -0.1$ mA to $-1$ mA | — | 1 | 10 | mV |
| **U.V.L.O. block** | | | | | | |
| Circuit operation start voltage | $V_{UON}$ | — | 2.8 | 3.1 | 3.4 | V |
| Hysteresis width | $V_{HYS}$ | — | 60 | 140 | 180 | mV |
| **Error amplifier block** | | | | | | |
| Input offset voltage | $V_{IO}$ | — | −6 | — | 6 | mV |
| Input bias current | $I_B$ | — | −500 | −25 | — | nA |
| Common-mode input voltage range | $V_{ICR}$ | — | −0.1 | — | 0.8 | V |
| High-level output voltage | $V_{EH}$ | — | $V_{REF}$ − 0.3 | $V_{REF}$ − 0.1 | — | V |
| Low-level output voltage | $V_{EL}$ | — | — | 0.1 | 0.3 | V |
| **Dead-time control circuit block** | | | | | | |
| Input current | $I_{DTC}$ | — | −15.8 | −13.2 | −10.6 | μA |
| Low-level input threshold voltage | $V_{DT-L}$ | Duty 0% | — | 0.45 | 0.65 | V |
| High-level input threshold voltage | $V_{DT-H}$ | Duty 100% | 1.2 | 1.4 | — | V |
| **Output block** | | | | | | |
| Oscillator frequency | $f_{OUT}$ | $C_T = 120$ pF, $R_T = 15$ kΩ | 196 | 218 | 240 | kHz |
| Output duty | Du | $R_{DTC} = 75$ kΩ | 47 | 52 | 57 | % |
| Low-level output voltage | $V_{OL}$ | $I_O = 70$ mA | — | 1.0 | 1.3 | V |
| High-level output voltage | $V_{OH}$ | $I_O = -70$ mA | $V_{CB}$ −2.0 | $V_{CB}$ −1.0 | — | V |
| **Bootstrap circuit block** | | | | | | |
| Input standby voltage | $V_{INCB}$ | $I_{CB} = -70$ mA | $V_{CC}$ −1.2 | $V_{CC}$ −1.0 | $V_{CC}$ − 0.8 | V |
| **Short-circuit protection circuit block** | | | | | | |
| Input threshold voltage | $V_{THPC}$ | — | 0.70 | 0.75 | 0.80 | V |
| Input standby voltage | $V_{STBY}$ | — | — | 30 | 120 | mV |
| Input latch voltage | $V_{IN}$ | — | — | 30 | 120 | mV |
| Charge current | $I_{CHG}$ | — | −2.76 | −2.30 | −1.84 | μA |
| **On/off control block** | | | | | | |
| Threshold voltage | $V_{TH}$ | — | 0.8 | — | 2.0 | V |
| **Overcurrent protection block** | | | | | | |
| Threshold voltage | $V_{CLM}$ | — | $V_{CC}$ − 0.115 | $V_{CC}$ − 0.095 | $V_{CC}$ − 0.075 | V |

## ■ Electrical Characteristics at $V_{CC} = 12$ V, $T_a = 25°C$ (continued)

| Parameter | Symbol | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Whole device | | | | | | |
| Total consumption current | $I_{CC}$ | — | — | 5.0 | 7.0 | mA |
| Standby current | $I_{CC(SB)}$ | — | — | — | 5 | μA |

- Design reference data

Note) The characteristics listed below are theoretical values based on the IC design and are not guaranteed.

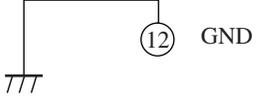| Parameter | Symbol | Conditions | Limit | Unit |
|---|---|---|---|---|
| Reference voltage block | | | | |
| Output voltage temperature characteristics 1 | $V_{TC1}$ | $T_a = -30°C$ to $+25°C$ | ±1 | % |
| Output voltage temperature characteristics 2 | $V_{TC2}$ | $T_a = 25°C$ to $85°C$ | ±1 | % |
| Output short-circuit current | $I_{OS}$ | — | −40 | mA |
| Error amplifier block | | | | |
| Output sink current | $I_{SINK}$ | $V_{FB} = 0.9$ V | 8 | mA |
| Output source current | $I_{SOURCE}$ | $V_{FB} = 0.9$ V | −110 | μA |
| Open-loop gain | $A_G$ | — | 70 | dB |
| Output block | | | | |
| Frequency supply voltage characteristics | $f_{dV}$ | $f_{OUT} = 200$ kHz, $V_{CC} = 3.6$ V to 34 V | ±3 | % |
| Frequency temperature characteristics 1 | $f_{dT1}$ | $f_{OUT} = 200$ kHz, $T_a = -30°C$ to $+25°C$ | ±9 | % |
| Frequency temperature characteristics 2 | $f_{dT2}$ | $f_{OUT} = 200$ kHz, $T_a = 25°C$ to $85°C$ | ±9 | % |
| Oscillator block | | | | |
| RT pin voltage | $V_{RT}$ | — | 0.4 | V |
| Short-circuit protection circuit block | | | | |
| Comparator threshold voltage | $V_{THL}$ | — | 1.87 | V |
| Overcurrent protection circuit block | | | | |
| Delay time | $t_{DLY}$ | — | 200 | ns |

■ Terminal Equivalent Circuits

| Pin No. | I / O | Equivalent circuit | Description |
|---|---|---|---|
| 1 | O |  | $V_{REF}$:<br>Outputs the reference voltage<br>     2.6 V (allowance: 3%)<br>Incorporating short-circuit protection against ground. |
| 2 | — |  | RT:<br>Connection for the timing resistor which decides the oscillator frequency. Use a resistor in the range 5.1 kΩ to 30 kΩ. The pin voltage is approx. 0.4 V. |
| 3 | — |  | CT:<br>Connection for the timing capacitor which decides the oscillator frequency. Use a capacitor in the range 100 pF to 10 000 pF. For the oscillator frequency setting, refer to the "Application Notes, [1] Function descriptions" section. Use an oscillator frequency in the range 5 kHz to 500 kHz. |
| 4 | — |  | DTC:<br>Connection for a resistor and a capacitor that set the dead-time and soft start period of PWM output.<br>Input current $I_{DTC}$ is decided by the timing resistor $R_T$ which controls sample to sample variations and temperature variations.<br>It is approx. −13.2 µA when $R_T$ = 15 kΩ.<br>$$I_{DTC} = \frac{V_{RT}}{R_T} \times \frac{1}{2} \text{ [A]}$$ |

■ Terminal Equivalent Circuits (continued)

| Pin No. | I / O | Equivalent circuit | Description |
|---|---|---|---|
| 5 | — |  | S.C.P.:<br>Connection for the capacitor that sets the soft start period and the timer latch short-circuit protection circuit time constant. Use a capacitor with a value of 1 000 pF or higher.<br>The charge current $I_{CHG}$ is decided by the timing resistor $R_T$ which controls sample to sample variations and temperature variations.<br>It is approx. $-2.3\ \mu A$ when $R_T = 15\ k\Omega$.<br>$$I_{CHG} = \frac{V_{RT}}{R_T} \times \frac{1}{11}\ [A]$$ |
| 6 | I |  | IN+:<br>Noninverting input to the error amplifier.<br>Use the common-mode input in the range $-0.1$ V to $+0.8$ V. |
| 7 | I | | IN−:<br>Inverting input to the error amplifier.<br>Use the common-mode input in the range $-0.1$ V to $+0.8$ V. |
| 8 | O |  | FB:<br>Output from the error amplifier.<br>The source current is approx. $-110\ \mu A$ and sink current is approx. 8 mA.<br>Correct the frequency characteristics of the gain and the phase by connecting a resistor and a capacitor between this pin and IN− pin. |
| 9 | — | — | N.C.: Not connected. |
| 10 | I |  | CLM:<br>Detects the overcurrent state in switching transistor.<br>Insert a resistor with a low resistance between this pin and $V_{CC}$ to detect overcurrent states. When this pin falls to a level 95 mV or more lower than $V_{CC}$, the PWM output is turned off for that period thus narrowing the width of the on-period.<br>(This implements a pulse-by-pulse overcurrent protection technique.) |

■ Terminal Equivalent Circuits (continued)

| Pin No. | I / O | Equivalent circuit | Description |
|---------|-------|--------------------|-------------|
| 11 | — |  ⑪ SGND | SGND: Signal ground. |
| 12 | — |  ⑫ GND | GND: Output stage ground. |
| 13 | O |  $V_{CC}$ ⑭ CB ⑬ Out | Out:<br>Totem pole output.<br>A constant output current of ±100 mA or a peak output current of ±1 A can be obtained. |
| 14 | O | | CB:<br>Bootstrap output.<br>Connect a bootstrap capacitor between this pin and the n-channel MOSFET source-side pin of the switching element when using a step-down voltage circuit.<br>Short-circuit this pin and the $V_{CC}$ pin when using a step-up voltage circuit. |
| 15 | I |  ⑮ $V_{CC}$ | $V_{CC}$: Power supply. |
| 16 | I |  $\overline{OFF}$ ⑯ 17 kΩ 13 kΩ | $\overline{OFF}$:<br>Controls the on/off state.<br>When the input is high: normal operation ($V_{\overline{OFF}} > 2.0$ V)<br>When the input is low: standby mode ($V_{\overline{OFF}} < 0.8$ V)<br>In standby mode, the total current consumption is held to under 10 µA. |
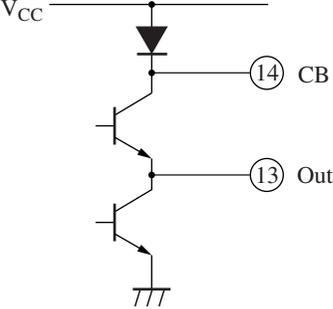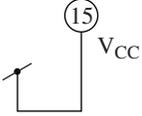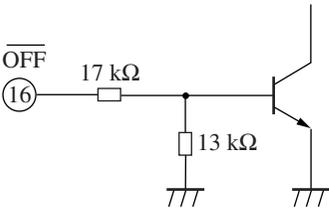
■ Application Notes

[1] Function descriptions

　1. Reference voltage block

　　　This block is composed of the band gap circuit and outputs the temperature compensated reference voltage (2.6 V) to the $V_{REF}$ pin (pin 1). The reference voltage is stabilized when the supply voltage is 3.6 V or more and used as the operating power supply in IC. It is possible to take out a load current of up to −1 mA.

■ Application Notes (continued)

[1] Function descriptions (continued)

2. The triangular wave generator block (OSC)

The triangular wave which swings from approximately 1.32 V (upper limit value, $V_{OSCH}$) to approximately 0.44 V (lower limit value, $V_{OSCL}$) will be generated by connecting a timing capacitor $C_T$ and a resistor $R_T$ to the $C_T$ pin (pin 3) and $R_T$ pin (pin 2) respectively. Oscillator frequency can be freely decided by the value of $C_T$ and $R_T$ connected externally. The oscillator frequency $f_{OSC}$ is obtained by the following formula;

$$f_{OSC} = \frac{1}{t_1 + t_2} = \frac{I_O}{2 \times C_T \times (V_{CTH} - V_{CHL})}$$

$$I_O = 1.7 \times \frac{V_{RT}}{R_T} = 1.7 \times \frac{0.4}{R_T}$$

Because  $V_{CTH} - V_{CTL} = 0.88$ V

$$f_{OSC} \approx \frac{1}{2.59 \times C_T \times R_T} \quad [\text{Hz}]$$

Example)  An $f_{OSC}$ of approximately 215 kHz will be obtained if $C_T$ is 120 pF and $R_T$ is 15 kΩ.
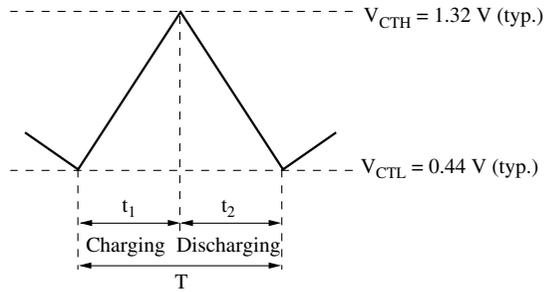


Figure 1.   Triangular oscillation waveform

It is possible to use the circuit in the recommended operating range of 5 kHz to 500 kHz of the oscillator frequency.  As the AN8014S is used at increasingly higher frequencies, the amount of overshoot and undershoot due to the operation delay in the triangular wave oscillator comparator increases, and discrepancies between the values calculated as described previously and the actual values may occur.

The output source currents of the AN8014S's S.C.P. and DTC pins are determined by the timing resistor $R_T$ which is externally connected to the RT pin. Therefore, note that this IC can not be used as an IC for slave when the several ICs are operated in parallel synchronous mode.

3. Error amplifier block

Detecting and amplifying DC-DC converter output voltage, the error amplifier with pnp transistor input inputs the signal to the PWM comparator.

Figure 2 shows the way to connect the error amplifier.

The common-mode input voltage range is − 0.1 V to + 0.8 V, and a voltage obtained by dividing the reference voltage with built-in resistors is applied to the non-inverting input. Connecting the feedback resistor and the capacitor between the error amplifier output pin (pin 8) and the inverting input pin (pin 7) allows the arbitrary gain setting and the phase compensation.

Startup overshooting caused by feedback delays will be suppressed by setting the output source current and output sink current to as high as 110 μA and 8 mA respectively.

The input voltage $V_{IN+}$ and $V_{IN-}$ to the error amplifier are obtained from the following formulas.

$$V_{IN+} = V_{REF} \times \frac{R_4}{R_3 + R_4} \qquad V_{IN-} = V_{OUT} \times \frac{R_2}{R_1 + R_2}$$
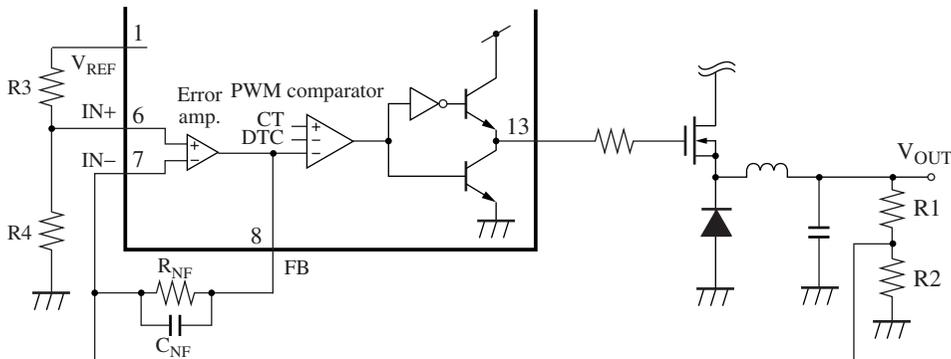


Figure 2.   Connection method of error amplifier

■ Application Notes (continued)

[1] Function descriptions (continued)

4. Timer latch short-circuit protection circuit

This circuit protects external main switching devices, flywheel diodes, choke coils and so forth from breakdown or deterioration when overload or short-circuit of power supply lasts a certain time.

Figure 3 shows the short-circuit protection circuit. The timer latch short-circuit protection circuit detects the output level of the error amplifier.

If the output voltage of the DC-DC converter is stable, the output of the error amplifier from the FB pin is stable and the short-circuit protection comparator is well balanced.

In that case, the transistor Q1 is conductive and the S.C.P. pin voltage is approximately 30 mV constantly.

If the load condition changes radically and output signal voltage of the error amplifier (FB) is 1.87 V or higher, the short-circuit protection comparator outputs low-level voltage. Then, by cutting off the transistor Q1, the external capacitor $C_S$ of S.C.P. pin (pin 5) starts charging with the current $I_{CHG}$ which is obtained from the following formulas.

$$V_{PE} = V_{STBY} + I_{CHG} \times \frac{t_{PE}}{C_S}\ \ [V]$$

$$0.75\ V = 0.03\ V + I_{CHG} \times \frac{t_{PE}}{C_S}$$

$$C_S = I_{CHG} \times \frac{t_{PE}}{0.72}\ \ [F]$$

$I_{CHG}$ is constant current which is determined by the timing resistor $R_T$ .

If $R_T$ is 15 kΩ, $I_{CHG}$ will be approximately 2.3 µA.

$$I_{CHG} = \frac{V_{RT}}{R_T} \times \frac{1}{11}\ \ [A]$$

When the external capacitor $C_S$ is charged up to approximately 0.75 V, the latch circuit will be turned on. Then the totem-pole output pin will be set to low level and the dead-time will be set to 100%.

When the latch circuit is turned on, the S.C.P. pin will discharge electricity till the voltage on the S.C.P. pin reduces to approximately 30 mV. The latch circuit cannot be, however, reset until power supply to the AN8014S is turned off.



Figure 3.   Short-circuit protection circuit

5. Low input voltage malfunction prevention circuit (U.V.L.O.)

This circuit protects system from breakdown or deterioration caused by malfunction in control circuit when supply voltage is dropped during transient time at power on or off.

The low input voltage malfunction prevention circuit detects internal reference voltage which changes in accordance with the supply voltage level. When the supply voltage is turned on, it sets the dead-time of Out pin (pin 13) to 100% and keeps the DTC pin (pin 4) and S.C.P. pin (pin 5) low level until the supply voltage reaches 3.1 V. When the supply voltage falls, it will operate even below 2.96 V because of its hysteresis width of 140 mV.

■ Application Notes (continued)

[1] Function descriptions (continued)

6. Remote circuit

It is possible to switch on or off the IC control by using an external control signal. When the $\overline{\text{OFF}}$ pin (pin 16) voltage is lowered to below approximately 0.8 V, the internal reference voltage goes down thereby stopping the IC control and reducing the circuit current to 5 µA or less. When the $\overline{\text{OFF}}$ pin voltage is increased to approximately 2.0 V or more, the internal reference voltage rises thereby starting the control operation.

7. PWM comparator block

The PWM comparator controls the on-period of output pulse in accordance with the input voltage. While the triangular wave voltage on the CT pin (pin 3) is lower than both the error amplifier's output voltage on pin 8 and the voltage on the DTC pin (pin 4), the output on the Out pin (pin 13) will be set to high level. Then the switching element (n-channel MOSFET) will be turned on.

The dead-time is set by adjusting the voltage $V_{DTC}$ on the DTC pin (pin 5) as shown in figure 4.

The DTC pin has constant current output determined by the resistor $R_T$. Therefore $V_{DTC}$ is adjusted by connecting the DTC and GND pins through the external resistor $R_{DTC}$.

When the oscillator frequency $f_{OSC}$ is 200 kHz, the output duty cycle will be 0% at $V_{DTC}$ of 0.44 V typical and 100% at $V_{DTC}$ of 1.32 V typical.

The levels of overshooting and undershooting of the peak value $V_{CTH}$ and the trough value $V_{CTL}$ of the triangular wave vary with the oscillator frequency.
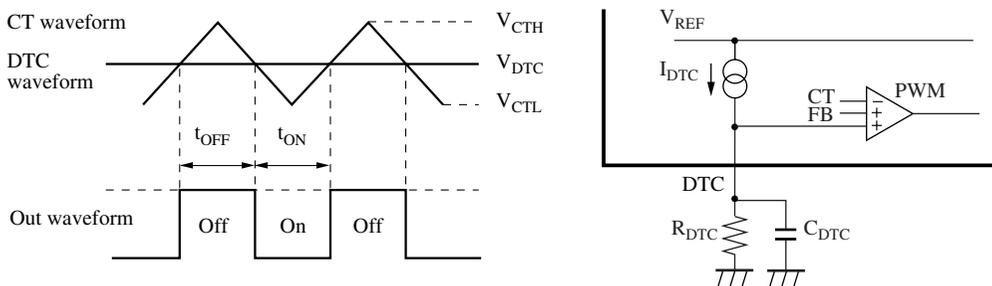


Figure 4. Setting the dead-time

Output duty ratio Du and DTC pin voltage $V_{DTC}$ are expressed by the following formulas;

$$Du = \frac{t_{ON}}{t_{ON} - t_{OFF}} \times 100 \ [\%] = \frac{V_{DTC} - V_{CTL} \times 1.1}{(V_{CTH} - V_{CTL}) \times 1.1} \times 100 \ [\%]$$

$$I_{DTC} = \frac{V_{RT}}{R_T} \times \frac{1}{2} \ [A]$$

$$V_{DTC} = I_{DTC} \times R_{DTC} = V_{RT} \times \frac{R_{DTC}}{R_T} \times \frac{1}{2} \ [V]$$

Example) When $f_{OSC} = 215$ [kHz] ($R_T = 15$ kΩ, $C_T = 120$ pF) and $R_{DTC} = 75$ [kΩ]

$V_{CTH}$ is approximately 1.32 V, $V_{CTH}$ is approximately 0.44 V, and $V_{RT}$ is approximately 0.4 V. Therefore, the following are obtained.

$I_{DTC} \approx 13.3$ [µA]

$V_{DTC} \approx 0.99$ [V]

Du ≈ 52.3 [%]

There may be an operational delay of the PWM comparator and a difference in peak and trough values of the triangular wave oscillation. Discrepancies between the values obtained from the above formulas and the actual values may occur, in which case adjust the values on the mounting substrate.

In starting, if the capacitor $C_{DTC}$ is added in parallel to the external resistor $R_{DTC}$, and the output pulse width are gradually widened, the AN8014S will be in soft-start operation. Thus the overshoot at the output of DC-DC converters can be prevented.

## ■ Application Notes (continued)

### [1] Function descriptions (continued)

#### 8. Overcurrent protection block

Utilizing that the overcurrent of power output is proportional to the current value which flows in the main switch (power MOSFET), the block regulates the upper limit of the current flowing in the main switch, thus protects the parts such as main switch device, a flywheel diode and a choke coil from the damage caused by the overcurrent.

The current detection are done by monitoring, at CLM pin (pin 10), the voltage drop in resistor which is placed between the main switch device and $V_{CC}$ pin.

When the main switch device (power MOSFET) is switched on and the voltage of CLM pin reaches "$V_{CC} -$ 95 mV", threshold level for overcurrent detection, the output drive transistor is cut off so that no more current flows in the main switch device. This control is repeated at each cycle. When overcurrent is detected once, the transistor remains off during the same cycle, and is switched on in the next cycle.

Such an overcurrent detection method is called "Pulse-by-pulse overcurrent detection."
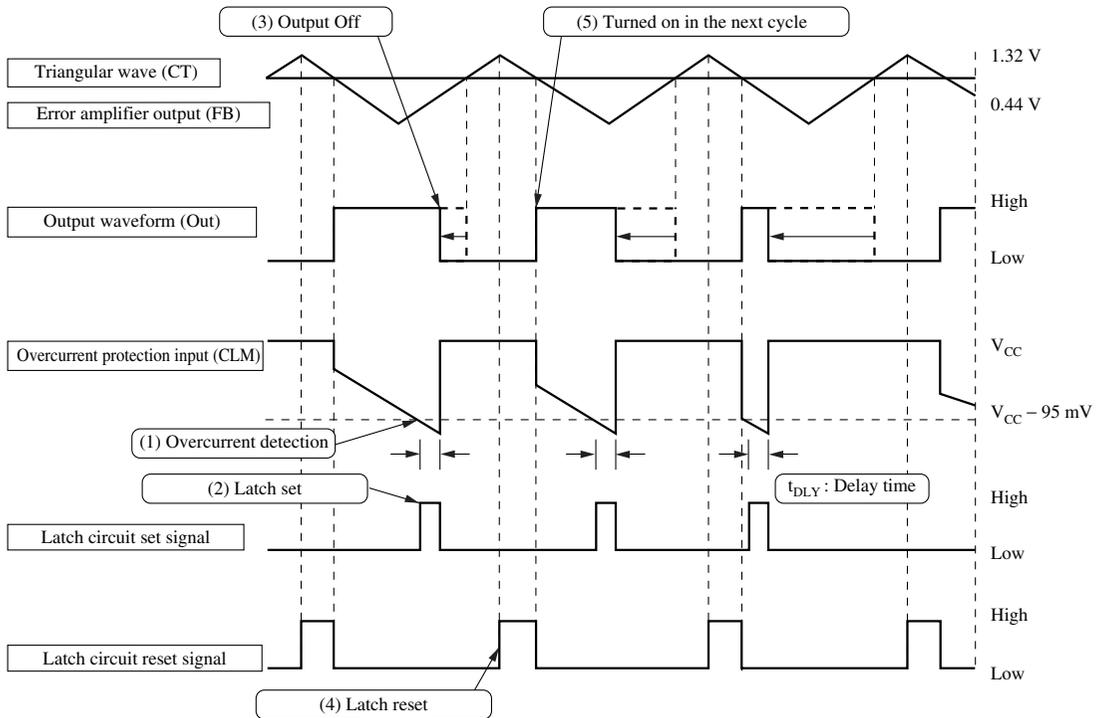
Figure 5.　Waveforms of the pulse-by-pulse overcurrent protection operation

R2 and C1 shown in figure 6 constitute a low-pass filter to eliminate noise due to parasitic capacitance when the power MOSFET is turned on.

The cut-off frequency of the filter is obtained from the following.

$$f_C = \frac{1}{2\pi C_1 R_2} \ \ [Hz]$$
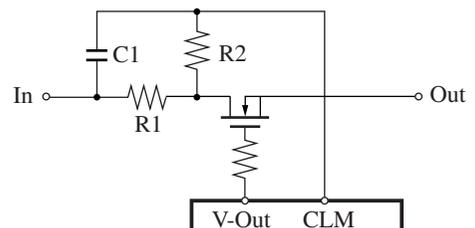
Figure 6.　CLM noise filter circuit

■ Application Notes (continued)

[1]  Function descriptions (continued)

   9.  Bootstrap circuit of output block

         If the n-channel MOSFET is used as a switching device for DC-DC converter control of step down method, a bootstrap circuit is required.

         Bootstrap circuit ensures that the gate-source voltage is gate threshold voltage or higher by going up the high level of the Out pin (pin 13) than $V_{CC}$ voltage when n-channel MOSFET turns on. Figure 7 shows the output of bootstrap circuit including the external circuit. Figure 8 shows the operating waveform of the bootstrap circuit.
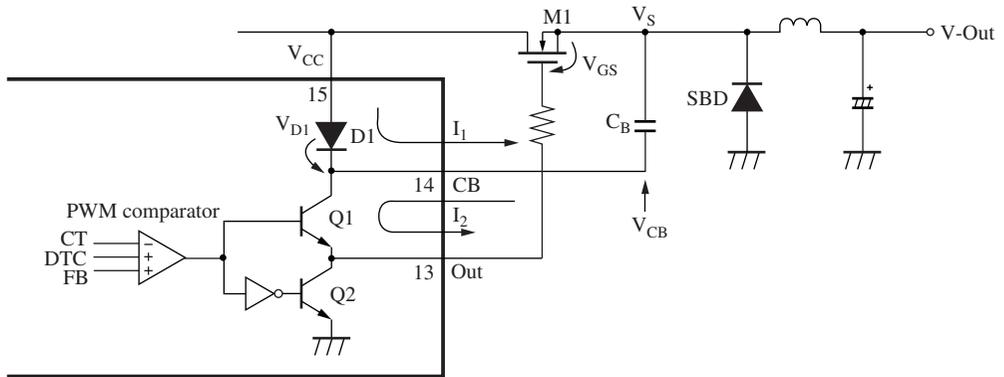
Figure 7.  Bootstrap circuit of output block
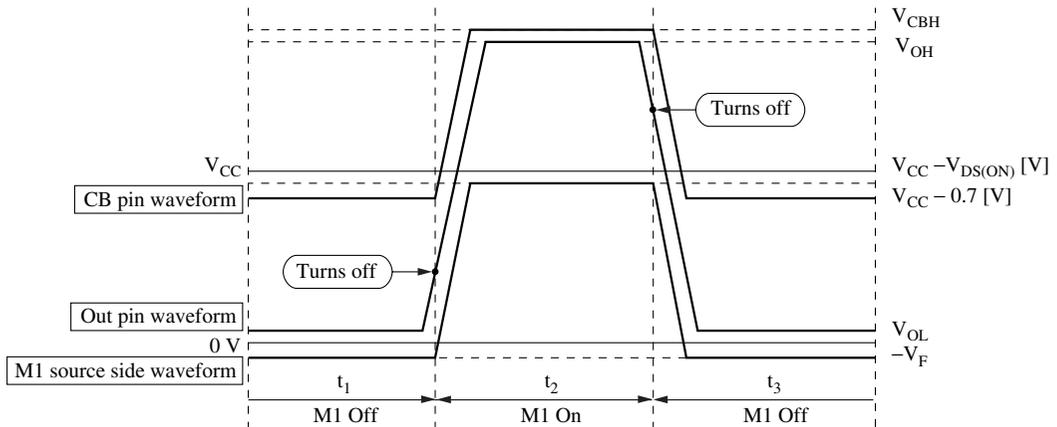
Figure 8.  Bootstrap circuit operating waveform

         The following describes the operation of the bootstrap circuit.

   1)  N-channel MOSFET (M1) off time: $t_1$

         While the M1 is turned off, the choke coil is provided with energy from the Schottky barrier diode (SBD) and the source-side voltage $V_S$ of the M1 is fixed to $-V_F$. The bootstrap capacitor $C_B$ is charged from the $V_{CC}$ pin (pin 15) through the AN8014S's internal diode D1.

         The voltage $V_{CB}$ on the CB pin (pin 14) is expressed by the following.

   $V_S = -V_F$

   $V_{CB} = V_{CC} - V_{D1}$

        $V_F$  : Forward voltage of SBD

        $V_{D1}$: Forward voltage of D1

         Therefore, the charged voltage of bootstrap capacitor $C_B$ is expressed by the following.

   $V_{CB} - V_S = V_{CC} - V_{D1} + V_F$

■ Application Notes (continued)

[1] Function descriptions (continued)

  9. Bootstrap circuit of output block (continued)

    2) N-channel MOSFET (M1) turn-on time: $t_2$

When the PWM comparator output is inverted, the Out pin (pin 13) output changes into a high level. The Out pin voltage $V_O$ rises toward the CB pin voltage.

$$V_O = V_{CB} - V_{CE}(sat)$$

Then the voltage between the gate and source of the M1 is obtained from the following.

$$V_{GS} = V_O + V_F$$

When the Out pin voltage $V_O$ is the same as or higher than the gate threshold voltage $V_{TH}$, the M1 turns on. Then the M1 source-side voltage rises up to the voltage expressed by the following.

$$V_S = V_{CC} - V_{DS(ON)}$$

The bootstrap capacitor $C_B$ is connected to the source side and CB pin of the M1. Therefore, the CB pin voltage rises according to the M1 source-side voltage due to capacitor coupling. $V_{CB}$ is expressed by the following formula.

$$V_{CB} = V_S + V_{CC} - V_{D1} + V_F$$
$$= 2 \times V_{CC} - V_{D1} + V_{DS(ON)} + V_F$$

    3) N-channel MOSFET (M1) turn-off time: $t_3$

The Out pin voltage turns off after rising to the saturation voltage of the AN8014S's internal transistor Q1. The M1 source-side voltage drops to $-V_F$. The CB pin voltage drops to $V_{CC} - V_{D1}$ or below due to capacitive coupling. Then the M1 will be in the state described in the above 1).

[2] Bootstrap circuit usage notes

  1. Operating voltage range for step-down circuit

Just like what described previously, if a step-down circuit is in DC-DC converter control, the CB pin (pin 14) voltage will be approximately twice as high as $V_{CC}$ when the n-channel MOSFET as a switching element is turned on. The allowable voltage applied to the CB pin is 35 V. Therefore the operating supply voltage must be within a range between 3.6 V and 17 V.

$$V_{CB} = 2 \times V_{CC} - V_{D1} - V_{DS(ON)} + V_F < 35 \ [V]$$
$$V_{CC} < \frac{35 + V_{D1} + V_{DS(ON)} - V_F}{2} \ [V] < 17 \ [V]$$

  2. Value setting of bootstrap capacitor

The bootstrap capacitor raises the CB pin voltage to $V_{CC}$ or higher due to capacitor coupling to the source side of the n-channel MOSFET when the n-channel MOSFET is turned on. At that time bootstrap capacitor is discharged by n-channel MOSFET gate-drive-current. If the capacitance of the bootstrap capacitor is too low, an increase in switching loss will result, which will reduce the efficiency.

Therefore, the capacitance must be large enough in comparison with the gate input capacitance of the n-channel MOSFET. Refer to the following.

$$C_B > C_{iss}$$

Determine the best value by testing on the printed circuit board for mounting.

  3. CB pin connection for step-up circuit

If a step-up circuit is in DC-DC converter control, no bootstrap circuit is required because the source side of the n-channel MOSFET is grounded. Therefore, short-circuit the CB pin (pin 14) and the $V_{CC}$ pin (pin 15).

Thus, the operating supply voltage range in the step-up circuit method is between 3.6 V and 34 V.

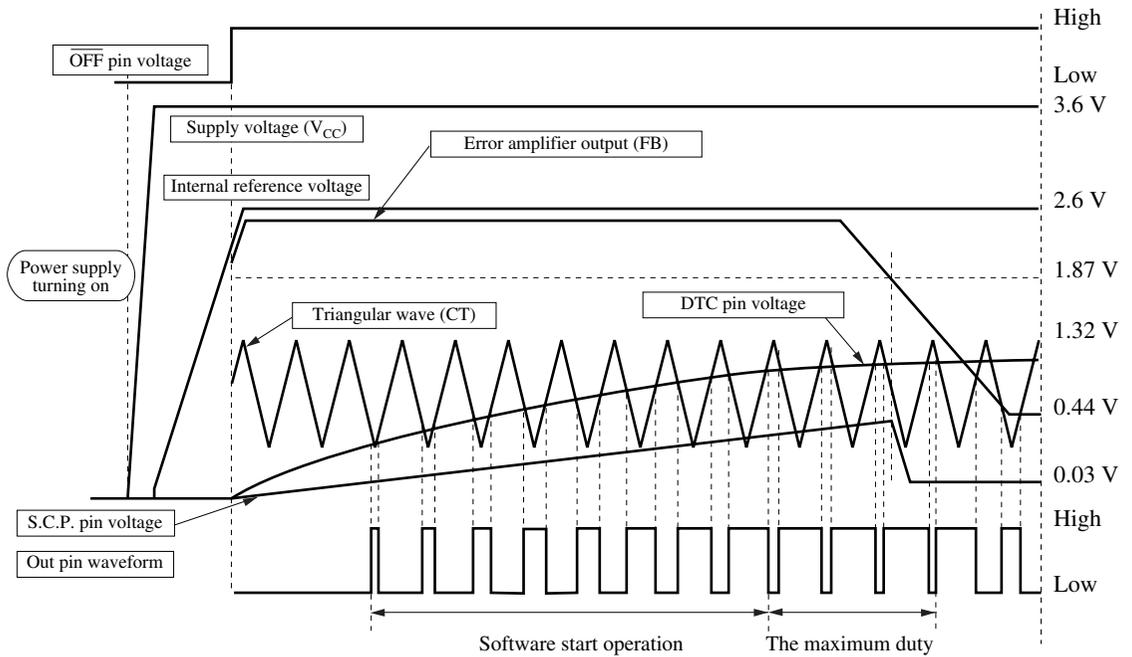■ Application Notes (continued)

[3]  Timing chart
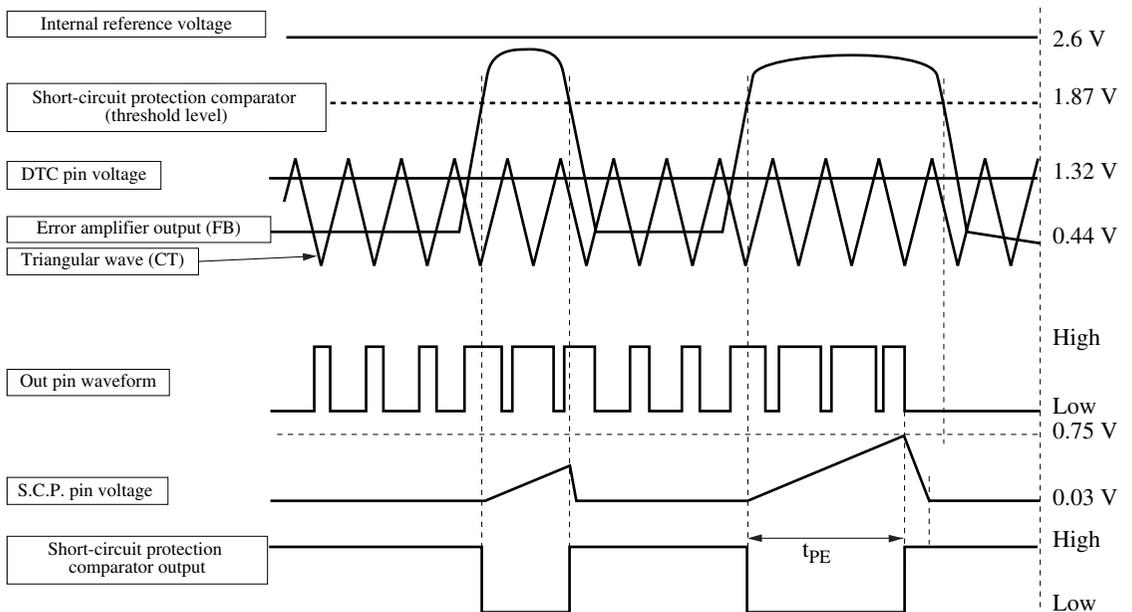


Figure 1.  PWM comparator operation waveform



Figure 2.  Short-circuit protection operation waveform

## ■ Application Notes (continued)

### [3] Timing chart (continued)
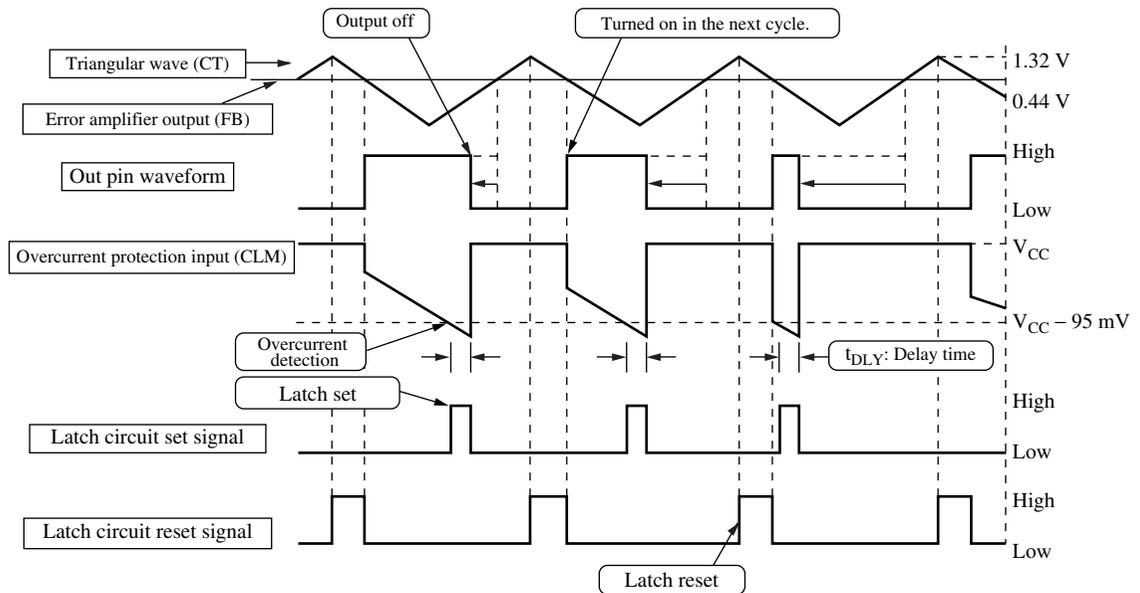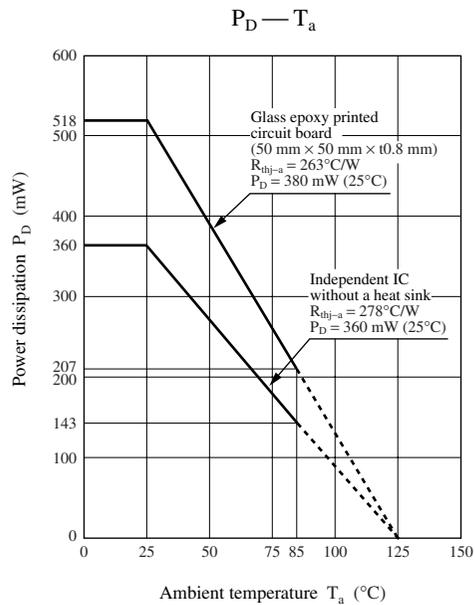
Triangular wave (CT)

Output off

Turned on in the next cycle.

Error amplifier output (FB)

1.32 V

0.44 V

Out pin waveform

High

Low

Overcurrent protection input (CLM)

$V_{CC}$

$V_{CC} - 95$ mV

Overcurrent detection

$t_{DLY}$: Delay time

Latch set

Latch circuit set signal

High

Low

Latch circuit reset signal

High

Low

Latch reset

Figure 3.   Waveforms of the pulse-by-pulse overcurrent protection operation

### [4]   $P_D$ — $T_a$ curves of SOP016-P-0225A

$$P_D — T_a$$

Glass epoxy printed circuit board
(50 mm × 50 mm × t0.8 mm)
$R_{thj-a} = 263°C/W$
$P_D = 380$ mW (25°C)

Independent IC without a heat sink
$R_{thj-a} = 278°C/W$
$P_D = 360$ mW (25°C)

Power dissipation $P_D$  (mW)

600
518
500
400
360
300
207
200
143
100
0

0    25    50    75  85   100    125    150

Ambient temperature  $T_a$  (°C)

■ Application Notes (continued)

[5] Main characteristics

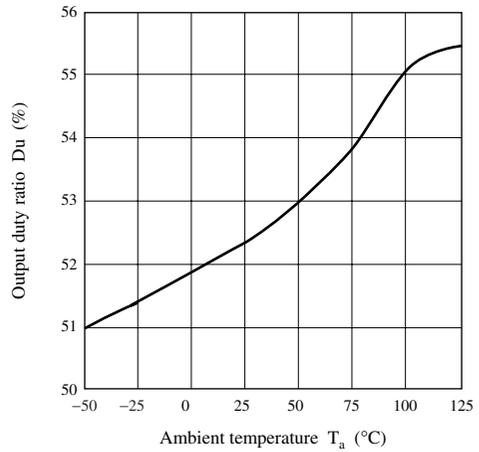Internal reference voltage temperature characteristics
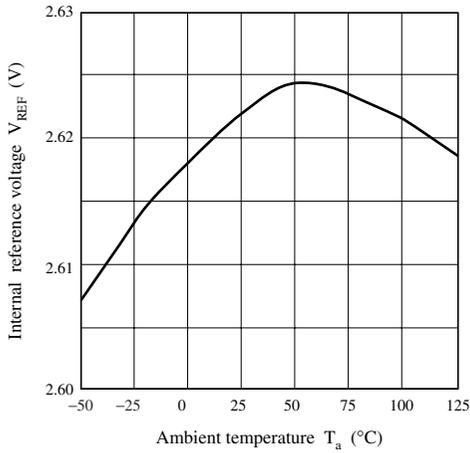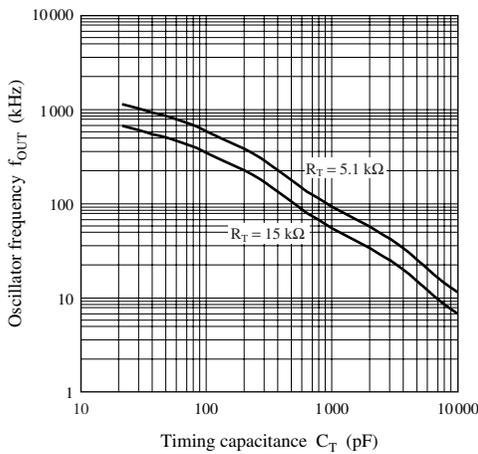
Oscillator frequency temperature characteristics
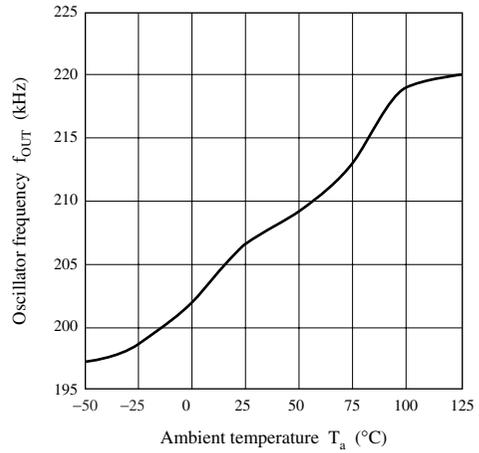
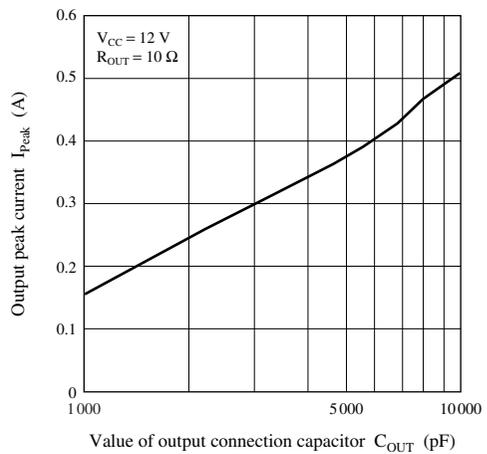Output duty ratio — DTC pin voltage
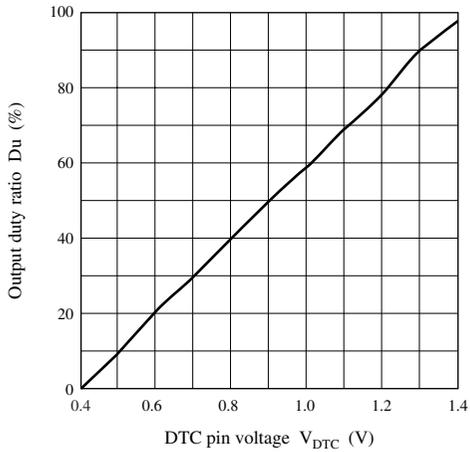
Output duty ratio temperature characteristics
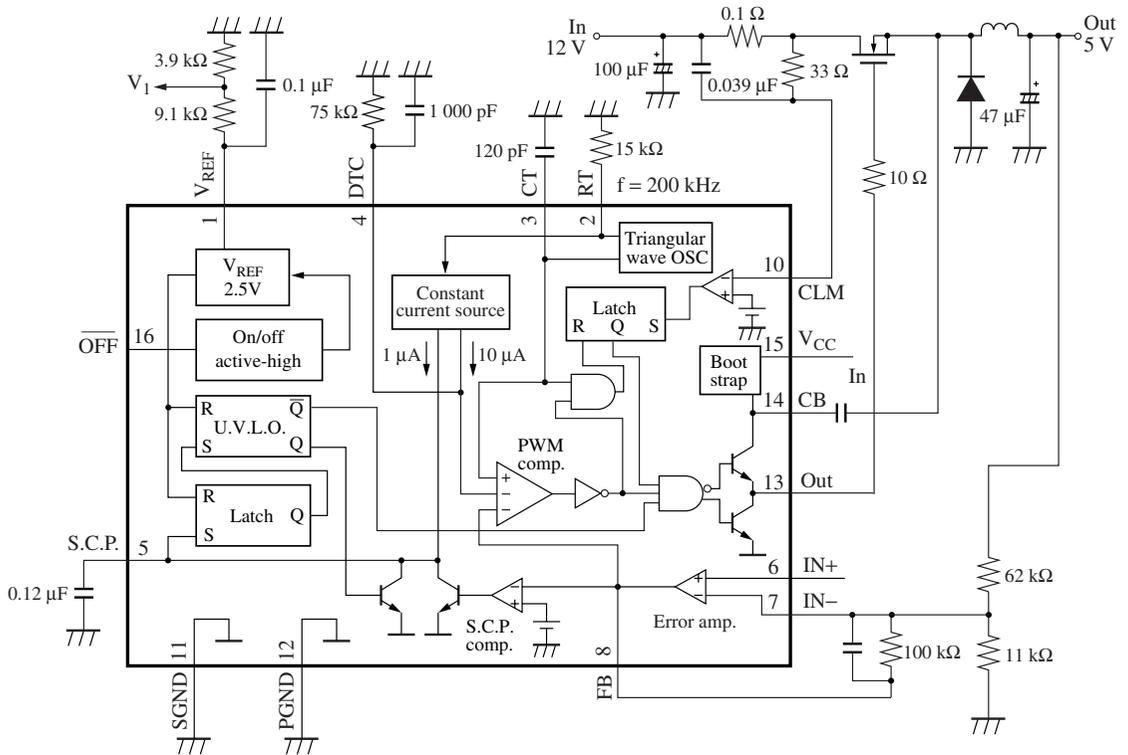
Oscillator frequency — Timing capacitance
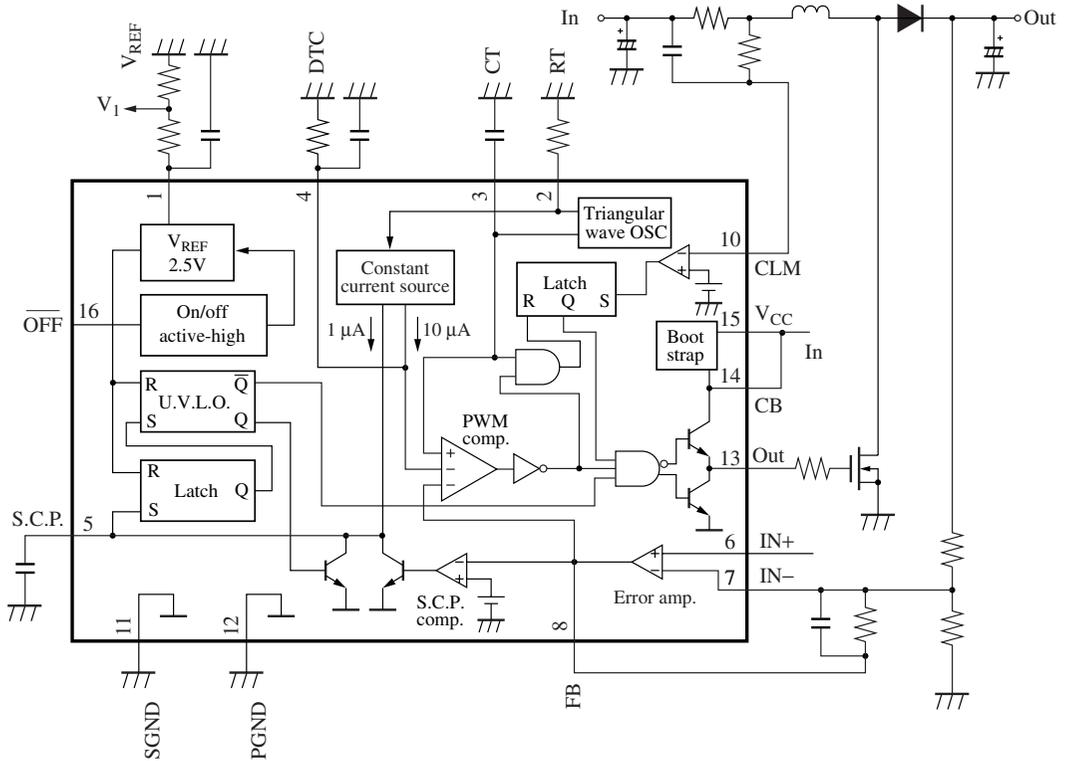
Output peak current — $C_{Out}$

## ■ Application Circuit Examples

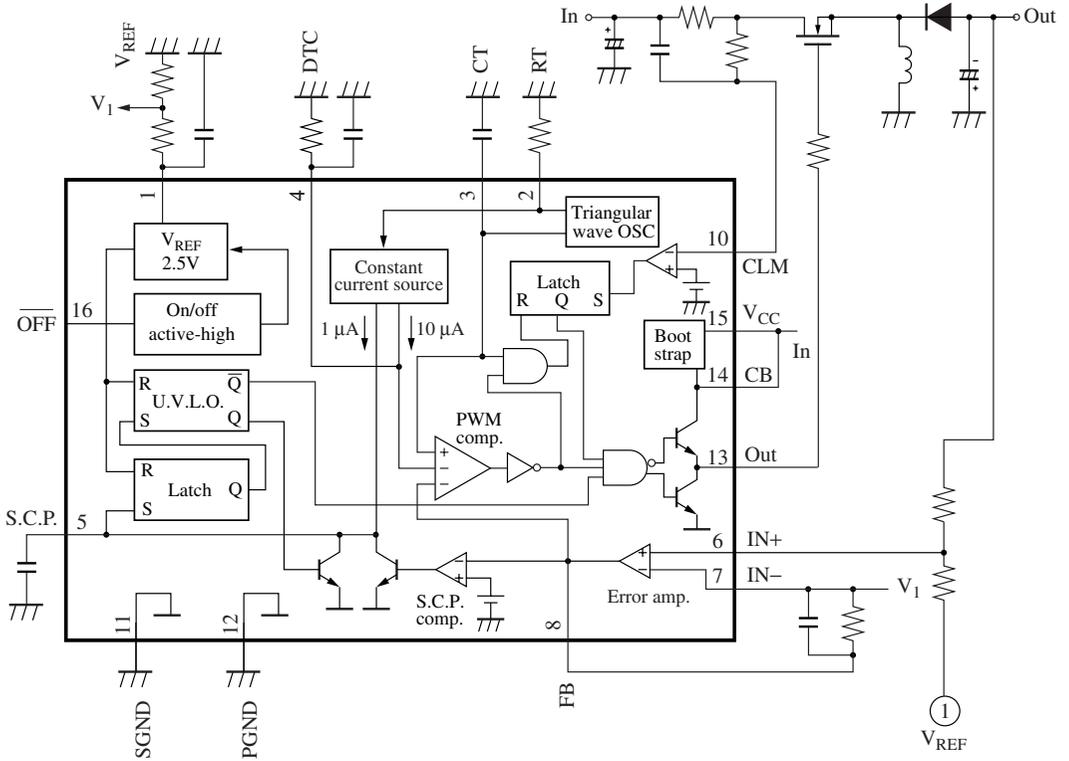### 1. DC-DC converter control (Example of step-down circuit)



### 2. DC-DC converter control (Example of step-up circuit)

■ Application Circuit Examples (continued)

3. DC-DC converter control (Example of polarity-inverting circuit)

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