DS04-27200-8E

ASSP For Power Management Applications

Switching Regulator Controller
(Switchable between push-pull and single-end functions)

MB3759

■ DESCRIPTION

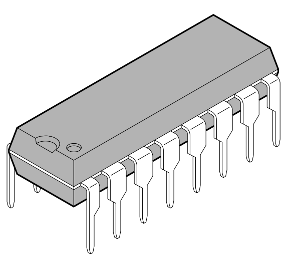
The MB3759 is a control IC for constant-frequency pulse width modulated switching regulators.
The IC contains most of the functions required for switching regulator control circuits. This reduces both the component count and assembly work.

■ FEATURES

- Drives a 200 mA load
- Can be set to push-pull or single-end operation
- Prevents double pulses
- Adjustable dead-time
- Error amplifier has wide common phase input range
- Built in a circuit to prevent misoperation due to low power supply voltage.
- Built in an internal 5 V reference voltage with superior voltage reduction characteristics

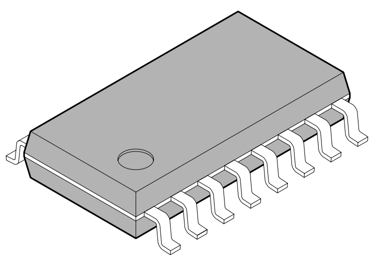
■ PACKAGES

16-pin plastic DIP



(DIP-16P-M04)

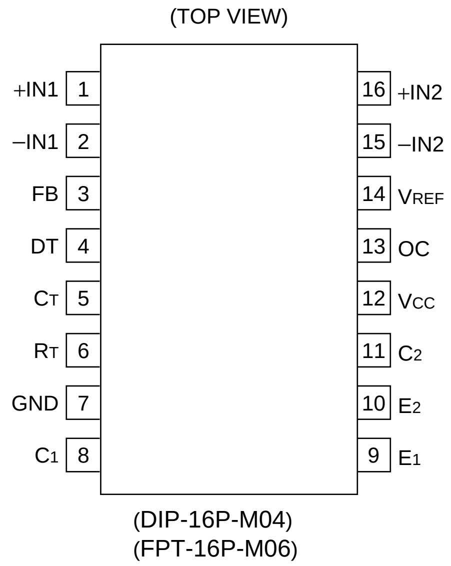
16-pin plastic SOP



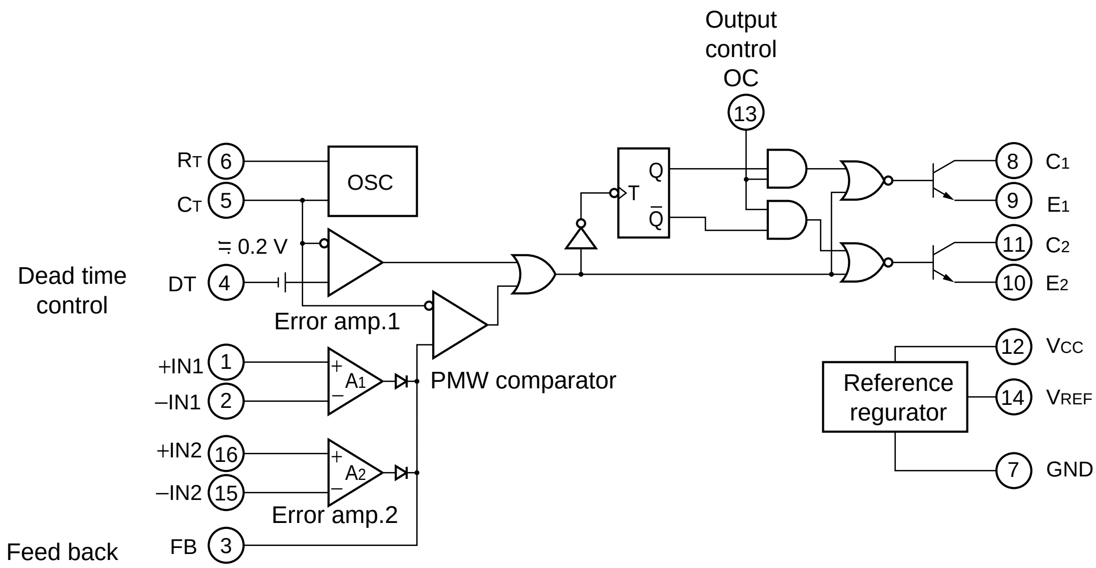
(FPT-16P-M06)

FUJITSU

■ PIN ASSIGNMENT



■ BLOCK DIAGRAM



■ ABSOLUTE MAXIMUM RATINGS

Parameter		Symbol	Condition	Rating		Unit
				Min	Max	
Power supply voltage		V_{CC}	—	—	41	V
Collector output voltage		V_{CE}	—	—	41	V
Collector output current		I_{CE}	—	—	250	mA
Amplifier input voltage		V_I	—	—	V_{CC} + 0.3	V
Power dissipation	Plastic DIP	P_D	Ta ≤ +25 °C	—	1000	mW
	SOP *			—	620	
Operating temperature		Top	—	–30	+85	°C
Storage temperature		Tstg	—	–55	+125	°C

*: When mounted on a 4 cm square double-sided epoxy circuit board (1.5 mm thickness)
The ceramic circuit board is 3 cm x 4 cm (0.5 mm thickness)

WARNING: Semiconductor devices can be permanently damaged by application of stress (voltage, current, temperature, etc.) in excess of absolute maximum ratings. Do not exceed these ratings.

■ RECOMMENDED OPERATING CONDITIONS

Parameter	Symbol	Value			Unit
		Min	Typ	Max	
Power supply voltage	V_{CC}	7	15	32	V
Collector output voltage	V_{CE}	—	—	40	V
Collector output current	I_{CE}	5	—	200	mA
Amplifier input voltage	V_{IN}	–0.3	0 to V_R	V_{CC} – 2	V
FB sink current	I_{SINK}	—	—	0.3	mA
FB source current	I_{SOURCE}	—	—	2	mA
Reference section output current	I_{REF}	—	5	10	mA
Timing resistor	R_T	1.8	30	500	kΩ
Timing capacitor	C_T	470	1000	10^6	pF
Oscillator frequency	fosc	1	40	300	kHz
Operating temperature	Top	–30	+25	+85	°C

Note: Values are for standard derating conditions. Give consideration to the ambient temperature and power consumption if using a high supply voltage.

WARNING: The recommended operating conditions are required in order to ensure the normal operation of the semiconductor device. All of the device’s electrical characteristics are warranted when the device is operated within these ranges.

Always use semiconductor devices within their recommended operating condition ranges. Operation outside these ranges may adversely affect reliability and could result in device failure.

No warranty is made with respect to uses, operating conditions, or combinations not represented on the data sheet. Users considering application outside the listed conditions are advised to contact their FUJITSU representatives beforehand.

■ ELECTRICAL CHARACTERISTICS

(V_{CC} = 15 V, Ta = +25 °C)

Parameter			Symbol	Condition	Value			Unit
					Min	Typ	Max	
Reference section	Output voltage		V_{REF}	I_O = 1 mA	4.75	5.0	5.25	V
	Input regulation		$\Delta V_{R(IN)}$	7 V ≤ V_{CC} ≤ 40 V, Ta = +25 °C	—	2	25	mV
	Load regulation		$\Delta V_{R(LD)}$	1 mA ≤ I_O ≤ 10 mA, Ta = +25 °C	—	–1	–15	mV
	Temperature stability		$\Delta V_R/\Delta T$	–20 °C ≤ Ta ≤ + 85 °C	—	±200	±750	µV/°C
	Short circuit output current		I_{SC}	—	15	40	—	mA
	Reference lockout voltage		—	—	—	4.3	—	V
	Reference hysteresis voltage		—	—	—	0.3	—	V
Oscillator section	Oscillator frequency		fosc	R_T = 30 kΩ, C_T = 1000 pF	36	40	44	kHz
	Standard deviation of frequency		—	R_T = 30 kΩ, C_T = 1000 pF	—	±3	—	%
	Frequency change with voltage		—	7 V ≤ V_{CC} ≤ 40 V, Ta = +25 °C	—	±0.1	—	%
	Frequency change with temperature		Δfosc/ΔT	–20 °C ≤ Ta ≤ +85 °C	—	±0.01	±0.03	%/°C
Dead-time control section	Input bias current		I_D	0 ≤ V_I ≤ 5.25 V	—	–2	–10	µA
	Maximum duty cycle (Each output)		—	V_I = 0	40	45	—	%
	Input threshold voltage	0% duty cycle	V_{DO}	—	—	3.0	3.3	V
		Max duty cycle	V_{DM}	—	0	—	—	V

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(V_{CC} = 15 V, Ta = +25 °C)

<table>
<tr><th colspan="3" rowspan="2">Parameter</th><th rowspan="2">Symbol</th><th rowspan="2">Condition</th><th colspan="3">Value</th><th rowspan="2">Unit</th></tr>
<tr><th>Min</th><th>Typ</th><th>Max</th></tr>
<tr><td rowspan="9">Error amplifier section</td><td colspan="2">Input offset voltage</td><td>V_{IO}</td><td>$V_{O\ (pin3)}$ = 2.5 V</td><td>—</td><td>±2</td><td>±10</td><td>mV</td></tr>
<tr><td colspan="2">Input offset current</td><td>I_{IO}</td><td>$V_{O\ (pin3)}$ = 2.5 V</td><td>—</td><td>±25</td><td>±250</td><td>nA</td></tr>
<tr><td colspan="2">Input bias current</td><td>I_I</td><td>$V_{O\ (pin3)}$ = 2.5 V</td><td>—</td><td>–0.2</td><td>–1.0</td><td>µA</td></tr>
<tr><td colspan="2">Common-mode input voltage</td><td>V_{CM}</td><td>7 V ≤ V_{CC} ≤ 40 V</td><td>–0.3</td><td>—</td><td>V_{CC} – 2</td><td>V</td></tr>
<tr><td colspan="2">Open-loop voltage amplification</td><td>A_V</td><td>0.5 V ≤ V_O ≤ 3.5 V</td><td>70</td><td>95</td><td>—</td><td>dB</td></tr>
<tr><td colspan="2">Unity-gain bandwidth</td><td>BW</td><td>A_V = 1</td><td>—</td><td>800</td><td>—</td><td>kHz</td></tr>
<tr><td colspan="2">Common-mode rejection ratio</td><td>CMR</td><td>V_{CC} = 40 V</td><td>65</td><td>80</td><td>—</td><td>dB</td></tr>
<tr><td rowspan="2">Output sink current (pin 3)</td><td>ISINK</td><td>I_{SINK}</td><td>-5 V ≤ V_{ID} ≤ -15 mV, V_O = 0.7 V</td><td>0.3</td><td>0.7</td><td>—</td><td>mA</td></tr>
<tr><td>ISOURCE</td><td>I_{SOURCE}</td><td>15 mV ≤ V_{ID} ≤ 5V, V_O = 3.5 V</td><td>–2</td><td>–10</td><td>—</td><td>mA</td></tr>
<tr><td rowspan="5">Output section</td><td colspan="2">Collector leakage current</td><td>I_{CO}</td><td>V_{CE} = 40 V, V_{CC} = 40 V</td><td>—</td><td>—</td><td>100</td><td>µA</td></tr>
<tr><td colspan="2">Emitter leakage current</td><td>I_{EO}</td><td>V_{CC} = V_C = 40 V, V_E = 0</td><td>—</td><td>—</td><td>–100</td><td>µA</td></tr>
<tr><td rowspan="2">Collector emitter saturation voltage</td><td>Emitter grounded</td><td>$V_{SAT(C)}$</td><td>V_E = 0, I_C = 200 mA</td><td>—</td><td>1.1</td><td>1.3</td><td>V</td></tr>
<tr><td>Emitter follower</td><td>$V_{SAT(E)}$</td><td>V_C = 15 V, I_E = –200 mA</td><td>—</td><td>1.5</td><td>2.5</td><td>V</td></tr>
<tr><td colspan="2">Output control input current</td><td>I_{OPC}</td><td>V_I = V_{REF}</td><td>—</td><td>1.3</td><td>3.5</td><td>mA</td></tr>
<tr><td rowspan="2">PWM comparator section</td><td colspan="2">Input threshold voltage</td><td>V_{TH}</td><td>0% Duty</td><td>—</td><td>4</td><td>4.5</td><td>V</td></tr>
<tr><td colspan="2">Input sink current (pin 3)</td><td>I_{SINK}</td><td>$V_{O\ (pin3)}$ = 0.7 V</td><td>0.3</td><td>0.7</td><td>—</td><td>mA</td></tr>
<tr><td colspan="3">Power supply current</td><td>I_{CC}</td><td>V(pin4) = 2 V, See "■ TEST CIRCUIT"</td><td>—</td><td>8</td><td>—</td><td>mA</td></tr>
<tr><td colspan="3">Standby current</td><td>I_{CCQ}</td><td>V(pin6) = V_{REF}, I/O open</td><td>—</td><td>7</td><td>12</td><td>mA</td></tr>
<tr><td rowspan="4">Switching characteristics</td><td>Rise time</td><td rowspan="2">Emitter grounded</td><td>t_R</td><td>R_L = 68 Ω</td><td>—</td><td>100</td><td>200</td><td>ns</td></tr>
<tr><td>Fall time</td><td>t_F</td><td>R_L = 68 Ω</td><td>—</td><td>25</td><td>100</td><td>ns</td></tr>
<tr><td>Rise time</td><td rowspan="2">Emitter follower</td><td>t_R</td><td>R_L = 68 Ω</td><td>—</td><td>100</td><td>200</td><td>ns</td></tr>
<tr><td>Fall time</td><td>t_F</td><td>R_L = 68 Ω</td><td>—</td><td>40</td><td>100</td><td>ns</td></tr>
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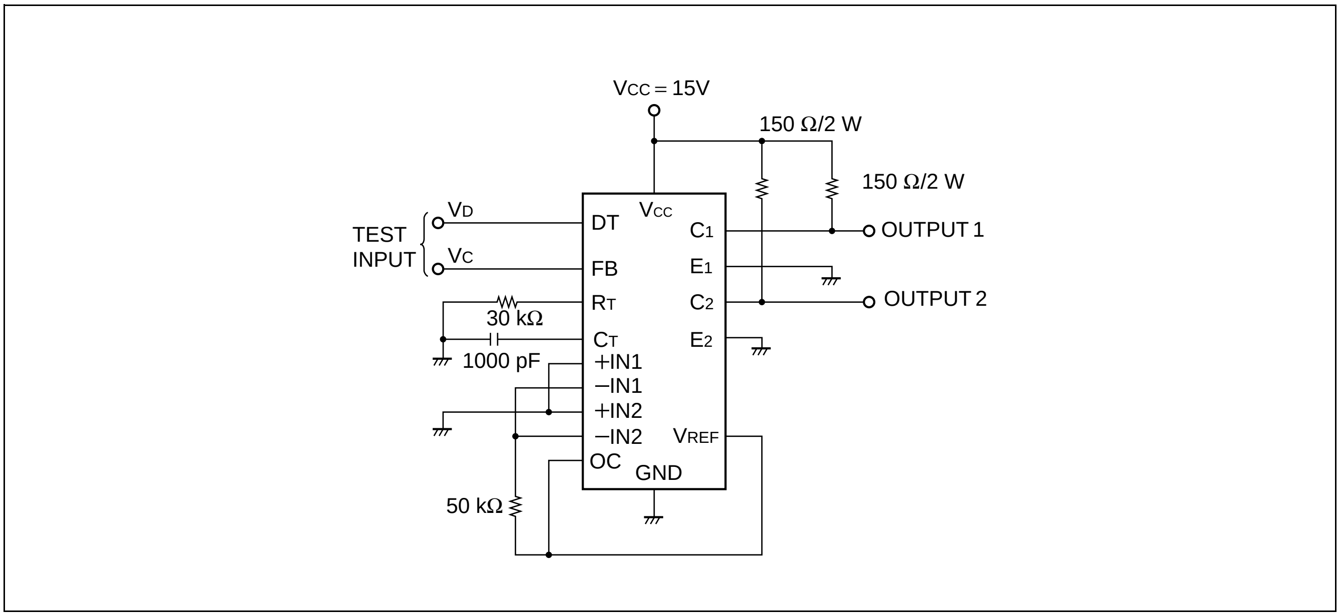
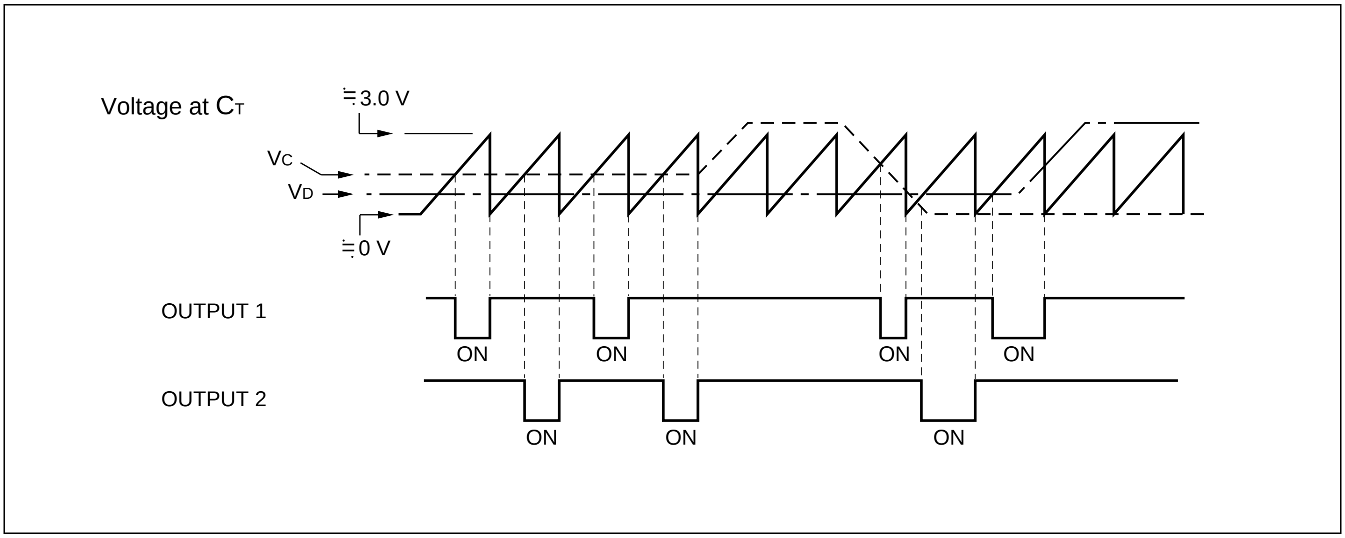
■ TEST CIRCUIT



■ OPERATING TIMING



■ OSCILLATION FREQUENCY

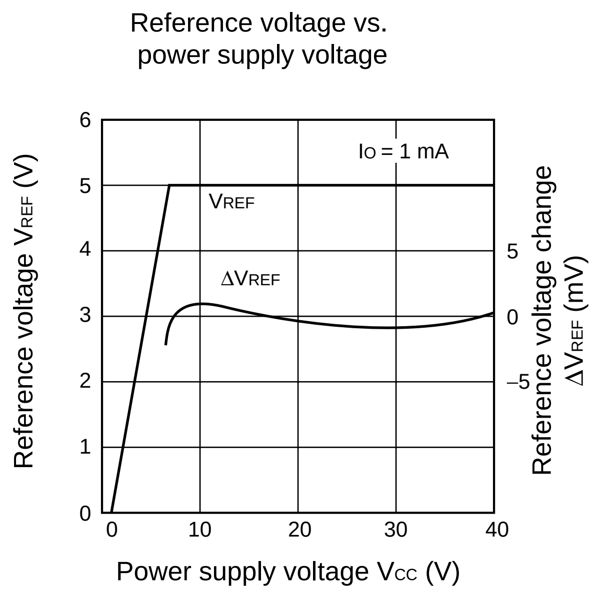
$$f_{OSC} \fallingdotseq \frac{1.2}{R_T \cdot C_T}$$

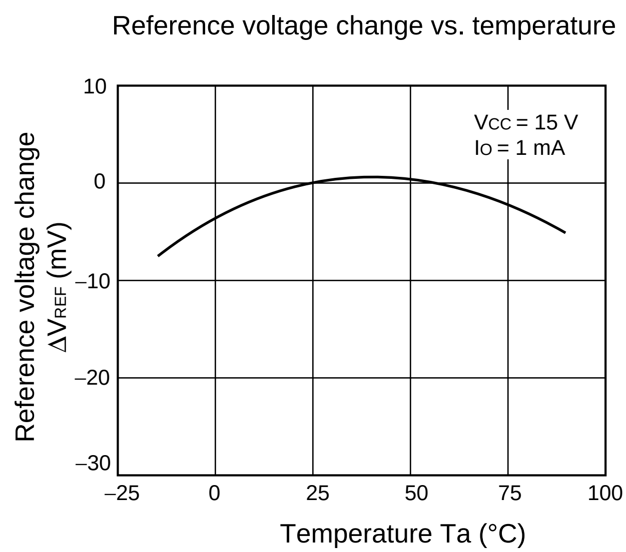
R_T : kΩ
C_T : µF
fosc : kHz

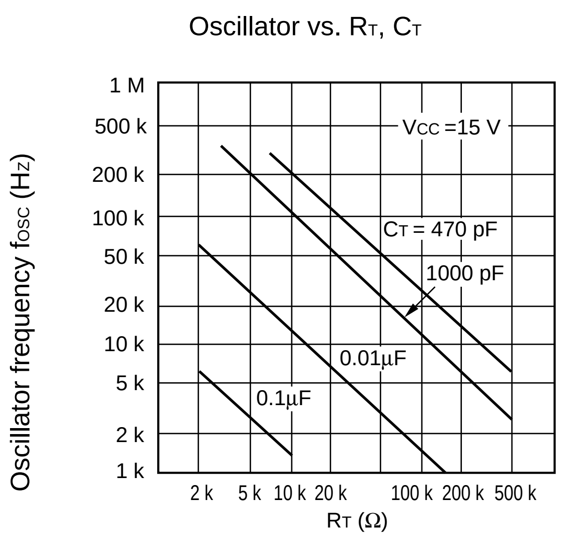
■ OUTPUT LOGIC TABLE

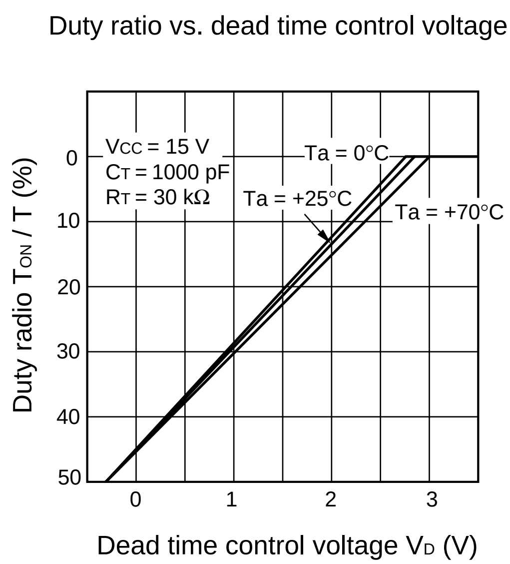
Input (Output Control)	Output State
GND	Single-ended or parallel output
V_{REF}	Push-pull

■ TYPICAL CHARACTERISTICS









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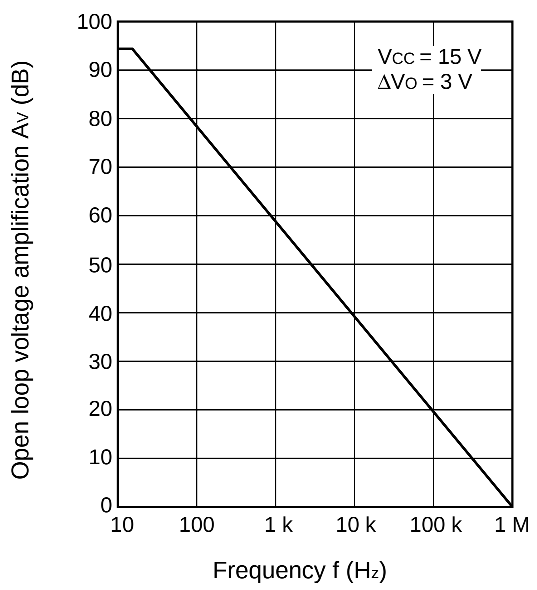
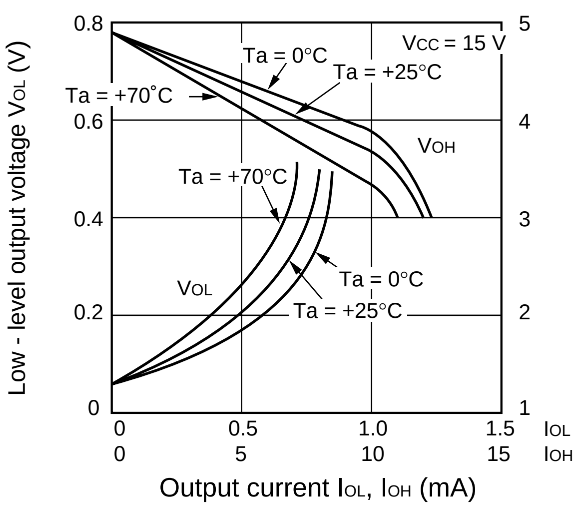
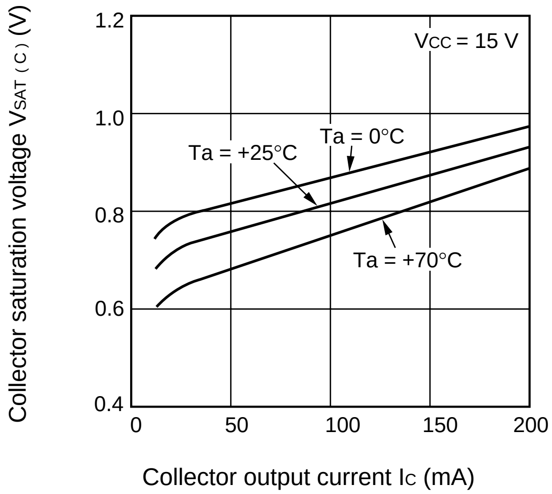
Open loop voltage amplification vs. frequency



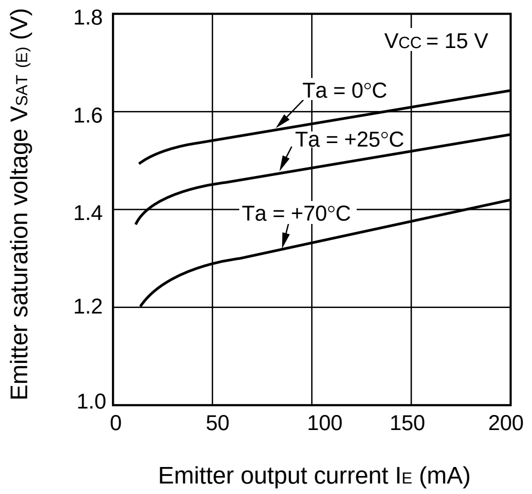
Output voltage vs. output current
(feed back terminal)



Collector saturation voltage vs.
collector output current



Emitter saturation voltage vs.
emitter output current



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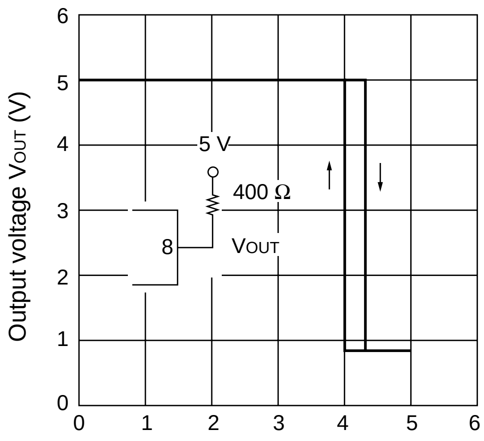
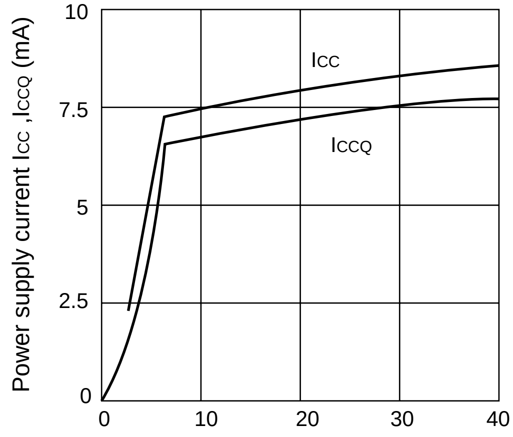
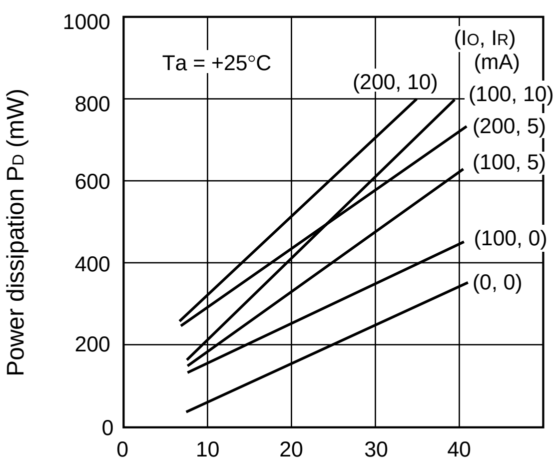
Output voltage vs. reference voltage



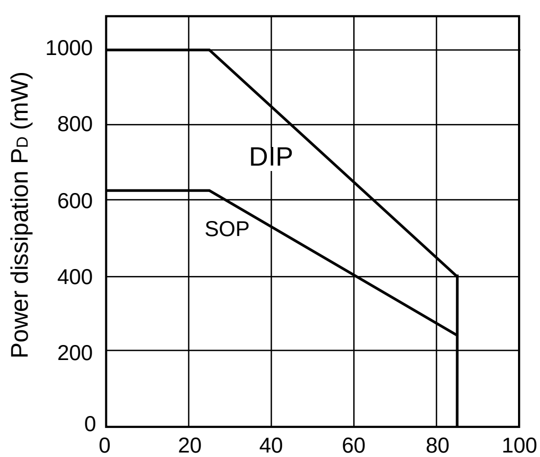
Power supply current vs. power supply voltage



Power dissipation vs. power supply voltage



Power dissipation vs. ambient temperature

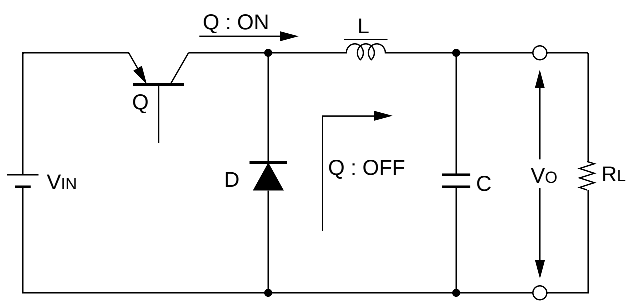


■ BASIC OPERATION

Switching regulators can achieve a high level of efficiency. This section describes the basic principles of operation using a chopper regulator as an example.
As shown in the diagram, diode D provides a current path for the current through inductance L when Q is off. Transistor Q performs switching and is operated at a frequency that provides a stable output. As the switching element is saturated when Q is on and cutoff when Q is off, the losses in the switching element are much less than for a series regulator in which the pass transistor is always in the active state.
While Q is conducting, the input voltage V_{IN} is supplied to the LC circuit and when Q is off, the energy stored in L is supplied to the load via diode D. The LC circuit smooths the input to supply the output voltage.

The output voltage V_O is given by the following equation.

$$V_O = \frac{Ton}{Ton + Toff} V_{IN} = \frac{Ton}{T} V_{IN}$$



Q: Switching element
D: Flywheel diode

As indicated by the equation, variation in the input voltage is compensated for by controlling the duty cycle (Ton/T). If V_{IN} drops, the control circuit operates to increase the duty cycle so as to keep the output voltage constant. The current through L flows from the input to the output when Q is on and through D when Q is off. Accordingly, the average input current I_{IN} is the product of the output current and the duty cycle for Q.

$$I_{IN} = \frac{Ton}{T} I_O$$

The theoretical conversion efficiency if the switching loss in Q and loss in D are ignored is as follows.

$$\begin{aligned}\eta &= \frac{P_O}{P_{IN}} \times 100\ (\%)\\ &= \frac{V_O \cdot I_O}{V_{IN} \cdot I_{IN}} \times 100\\ &= \frac{V_{IN} \cdot I_O \cdot Ton / T}{V_{IN} \cdot I_O \cdot Ton / T} \times 100\\ &= 100\ (\%)\end{aligned}$$

The theoretical conversion efficiency is 100%. In practice, losses occur in the switching element and elsewhere, and design decisions to minimize these losses include making the switching frequency as low as practical and setting an optimum ratio of input to output voltage.

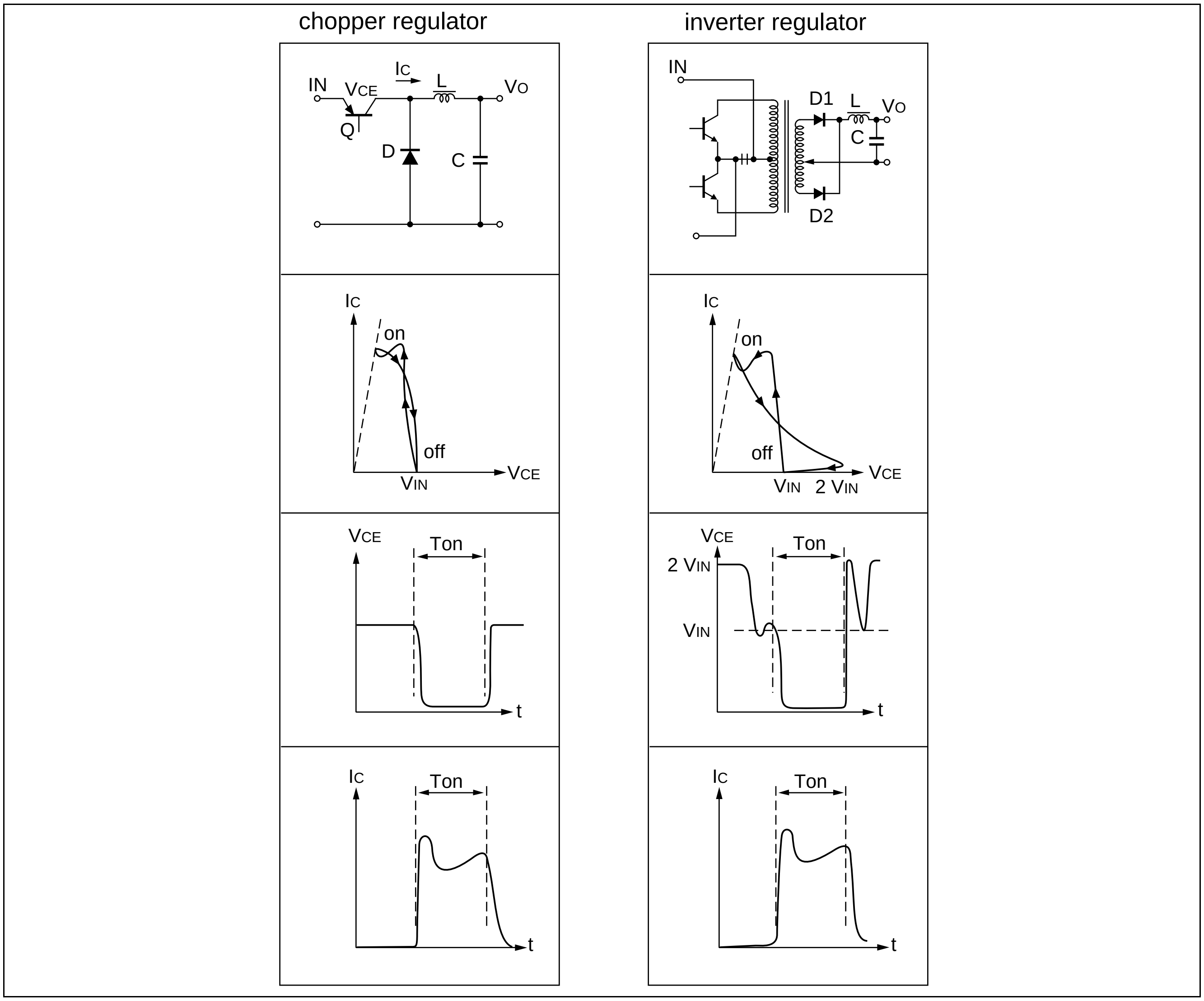
■ SWITCHING ELEMENT

1. Selection of the Switching Transistor

It can be said that the success or otherwise of a switching regulator is determined by the choice of switching transistor. Typically, the following parameters are considered in selecting a transistor.

- Withstand voltage
- Current
- Power
- Speed

For the withstand voltage, current, and power, it is necessary to determine that the area of safe operation (ASO) of the intended transistor covers the intended range for these parameters.
The speed (switching speed: rise time tr, storage time tstg, and fall time tf) is related to the efficiency and also influences the power.
The figures show the transistor load curve and V_{CE} - I_C waveforms for chopper and inverter-type regulators.
The chopper regulator is a relatively easy circuit to deal with as the diode clamps the collector. A peak can be seen immediately after turn-on. However, this is due to the diode and is explained later.
In an inverter regulator, the diodes on the secondary side act as a clamp. Viewed from the primary side, however, a leakage inductance is present. This results in an inductive spike which must be taken account of as it is added to double the V_{IN} voltage.

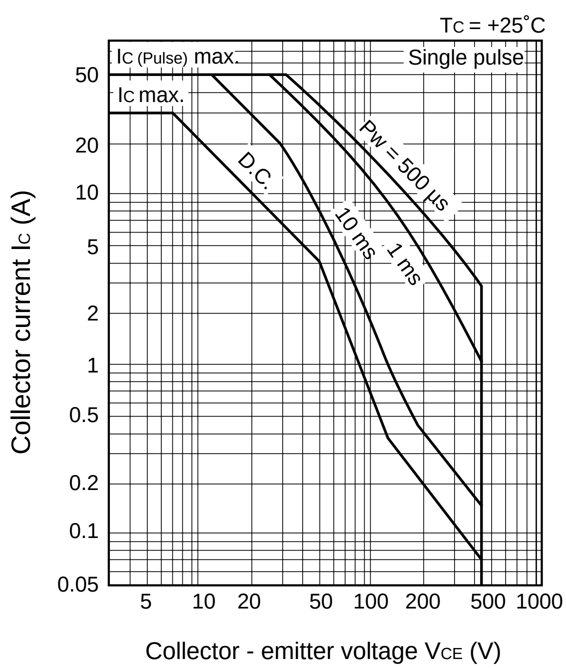


The figure below shows an example of the ASO characteristics for a forward-biased power transistor (2SC3058A) suitable for switching.
Check that the ASO characteristics for the transistor you intend to use fully covers the load curve. Next, check whether the following conditions are satisfied. If so, the transistor can be expected to perform the switching operation safely.

- The intended ON time does not exceed the ON-time specified for the ASO characteristic.
- The OFF-time ASO characteristic satisfies the intended operation conditions.
- Derating for the junction temperature has been taken into account.

For a switching transistor, the junction temperature is closely related to the switching speed. This is because the switching speed becomes slower as the temperature increases and this affects the switching losses.

Forward-biased area of safe operation single pulse



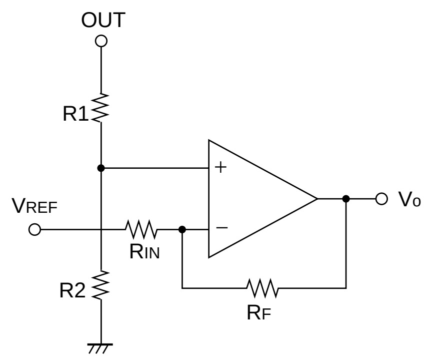
2. Selecting the Diode

Consideration must be given to the switching speed when selecting the diode. For chopper regulators in particular, the diode affects the efficiency and noise characteristics and has a big influence on the performance of the switching regulator.
If the reverse recovery time of the diode is slower than the turn-on time of the transistor, an in-rush current of more than twice the load current occurs resulting in noise (spikes) and reduced efficiency.
As a rule for diode selection, use a diode with a reverse recovery time t_{rr} that is sufficiently faster than the transistor t_r.

■ APPLICATION IN PRACTICAL CIRCUITS

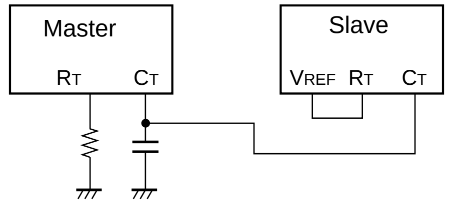
1. Error Amplifier Gain Adjustment

Take care that the bias current does not become large when connecting an external circuit to the FB pin (pin 3) for adjusting the amplifier gain. As the FB pin is biased to the low level by a sink current, the duty cycle of the output signal will be affected if the current from the external circuit is greater than the amplifier can sink.
The figure below shows a suitable circuit for adjusting the gain.
It is very important that you avoid having a capacitive load connected to the output stage as this will affect the response time.



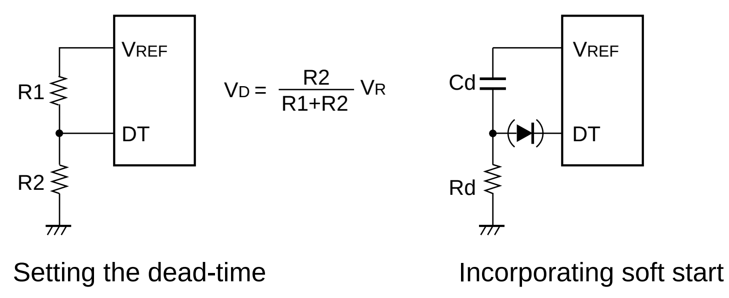
2. Synchronized Oscillator Operation

The oscillator can be halted by connecting the C_T pin to the GND pin. If supplying the signal externally, halt the internal oscillator and input to the C_T pin.
Using this method, multiple ICs can be used together in synchronized operation. For synchronized operation, set one IC as the master and connect the other ICs as shown in the diagram.

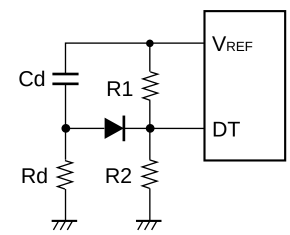


3. Soft Start

A soft start function can be incorporated by using the dead-time control element.

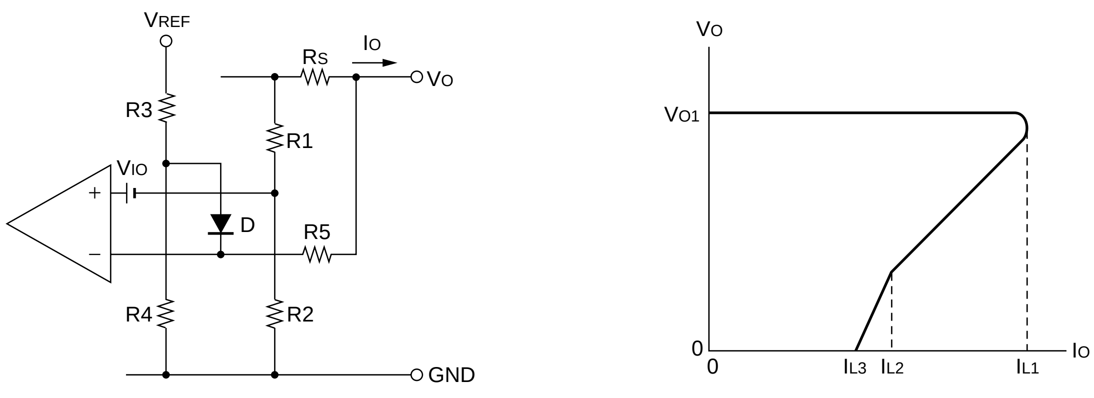


When the power is turned on, Cd is not yet charged and the DT input is pulled to the V_{REF} pin causing the output transistor to turn off. Next, the input voltage to the DT pin drops in accordance with the Cd, Rd constant causing the output pulse width to increase steadily, providing stable control circuit operation.
If you wish to use both dead-time and softstart, combine these in an OR configuration.



4. Output Current Limiting (Fallback system using a detection resistor inserted on the output side)

(1) Typical example



- Initial limit current I_{L1}

The condition for V_O is: $V_O > \frac{R4}{R3 + R4} V_{REF}$

As the diode is reverse biased,

$$R_S\ I_{L1} = \frac{R1}{R1 + R2} V_O - V_{IO}$$

$$\therefore I_{L1} = \frac{R1}{R1 + R2} \frac{V_O}{R_S} - \frac{V_{IO}}{R_S} \quad \text{Eq. (1) (where R2 >> R1)}$$

V_{IO} is the input offset voltage to the op-amp (-10 mV $\leq V_{IO} \leq$ +10 mV) and this causes the variation in I_L. Accordingly, if for example the variation in I_L is to be limited to $\pm$10 %, using equation (1) and only considering the variation in the offset voltage gives the following:

$$I_O = \frac{1}{R_S} \frac{R1}{R1 + R2} (V_O + V_{EE}) - \frac{V_{IO}}{R_S} \ (R2 >> R1)$$

This indicates a setting of 100 mV or more is required.

- Polarity change point I_{L2}

As this is the point where the diode becomes forward biased, it can be calculated by substituting [R4/(R3+R4) V_{REF} - V_D] for V_O in equation (where V_D is the forward voltage of the diode).

$$I_{L2} = \frac{R1}{R1 + R2} \frac{R4 / (R3 + R4) \cdot V_{REF} - V_D}{R_S} - \frac{V_{IO}}{R_S}$$

- Final limit current I_{L3}

The limit current for V_O = 0 when R2 >> R1 is the point where the voltages on either side of R_S and on either side of R5 are biased.

$$R_S\ I_{L3} = \frac{R4R5\ V_{REF} - R3R5\ V_D - R4R5\ V_D}{R3R4 + R3R5 + R4R5} - V_{IO}$$

$$\therefore I_{L3} = \frac{1}{R_S} \frac{1}{1 + (R_3 // R_4) / R_5} \left(\frac{R4}{R3 + R4} V_{REF} - V_D \right) - \frac{V_{IO}}{R_S} \quad \text{(2) Eq.}$$

R3//R4 is the resistance formed by R3 and R4 in parallel (R3R4/(R3 + R4)). When R3//R4 << R5, equation (2) becomes:

$$I_{L3\,C} = \frac{1}{R_S} \left(\frac{R4}{R3 + R4} V_{REF} - V_D \right) - \frac{V_{IO}}{R_S}$$

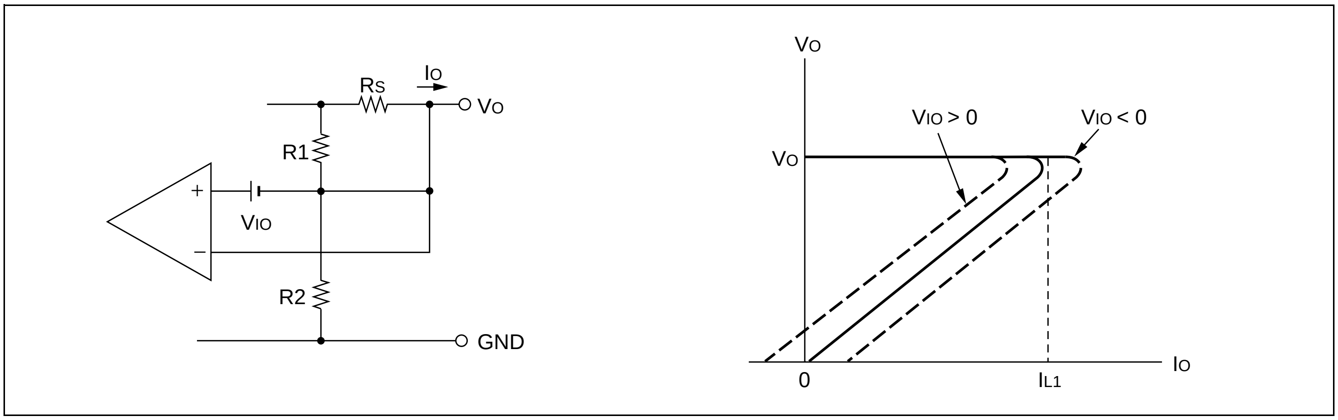
In addition to determining the limit current I_{L3} for V_O = 0, R3, R4, R5, and diode D also operate as a starter when the power is turned on.

- Starter circuit

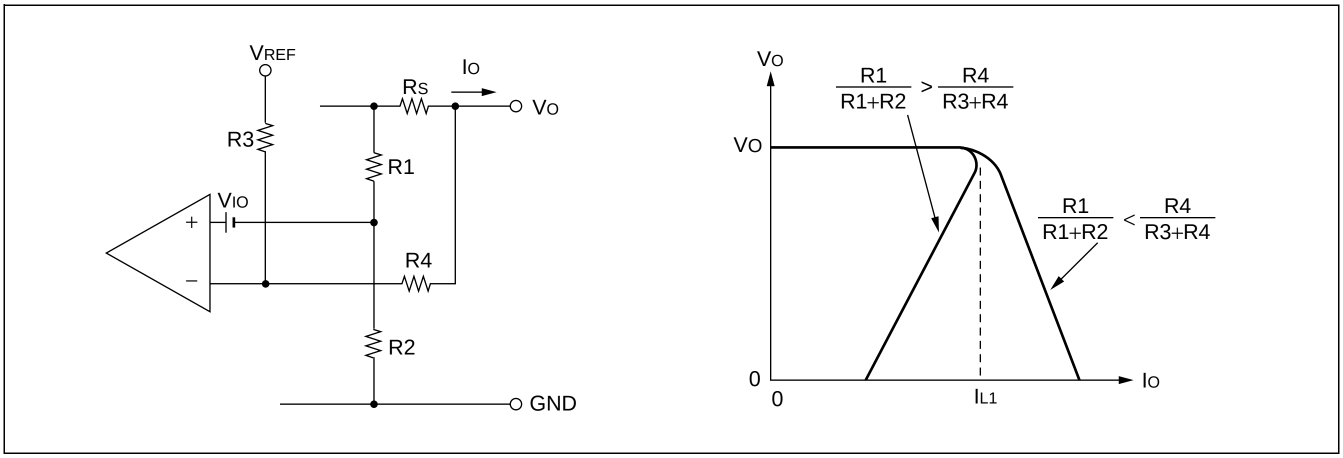
The figure below shows the case when the starter circuit formed by R3, R4, R5, and D is not present. The output current I_O after the operation of the current limiting circuit is:

$$I_O = \frac{R1}{R1 + R2} \frac{V_O}{R_S} - \frac{V_{IO}}{R_S}$$

When V_O = 0 such as when the power is turned on, the output current I_O = -V_{IO} / R_S and, if the offset voltage V_{IO} is positive, the output current is limited to being negative and therefore the output voltage does not rise.
Accordingly, if using a fallback system with a detection resistor inserted in the output, always include a starter circuit, expect in the cases described later.



(2) Example that does not use a diode

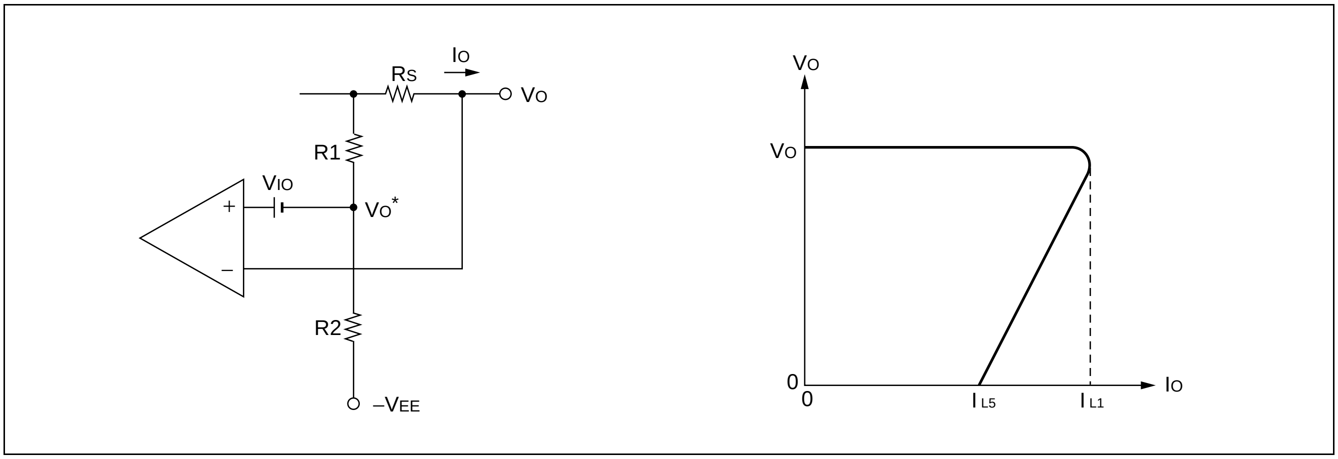


The output current I_O after current limiting is:

$$I_O = \frac{1}{R_S}\left[\left(\frac{R1}{R1 + R2} - \frac{R4}{R3 + R4}\right) V_O + \frac{R4}{R3 + R4} V_{REF} - V_{IO}\right] \ (R2 >> R1)$$

In this case, a current flows into the reference voltage source via R3 and R4 if $V_O > V_{REF}$. To maintain the stability of the reference voltage, design the circuit such that this does not exceed 200 µA.

(3) When an external stabilized negative power supply is present



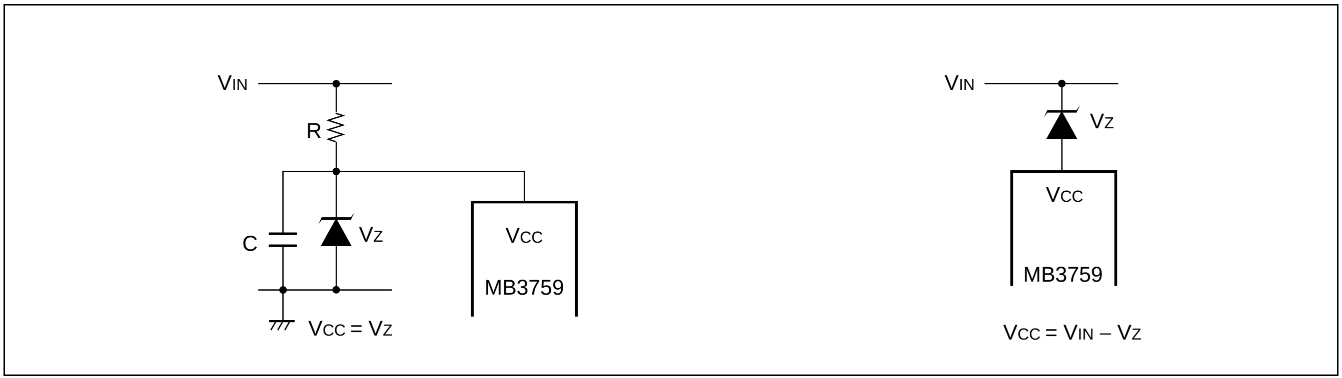
The output current I_O after current limiting is:

$$I_O = \frac{1}{R_S} \frac{R1}{R1 + R2} (V_O + V_{EE}) - \frac{V_{IO}}{R_S} (R2 >> R1)$$

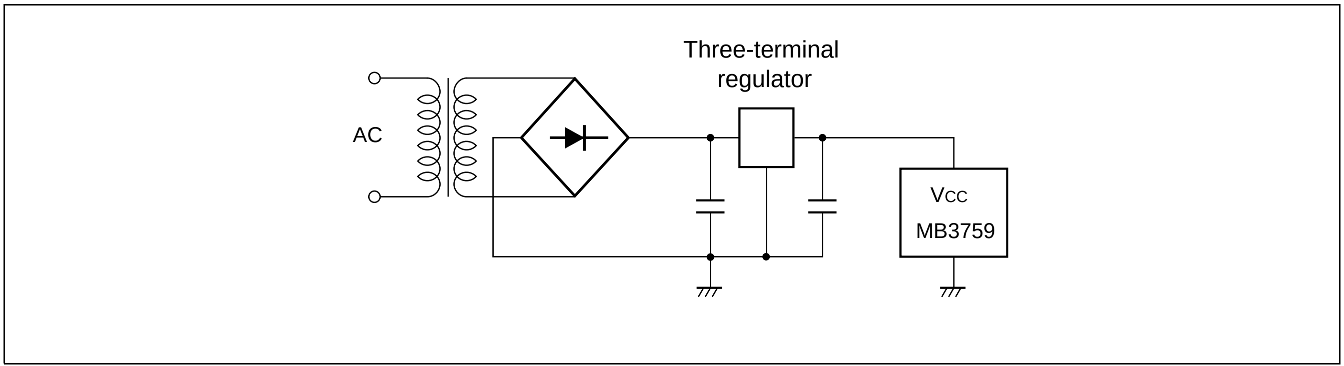
If the output is momentarily shorted, V_O* goes briefly negative. In this case, set the voltage across R1 to 300 mV or less to ensure that a voltage of less than -0.3 V is not applied to the op-amp input.

5. Example Power Supply Voltage Supply Circuit

(1) Supplied via a Zener diode



(2) Supplied via a three-terminal regulator

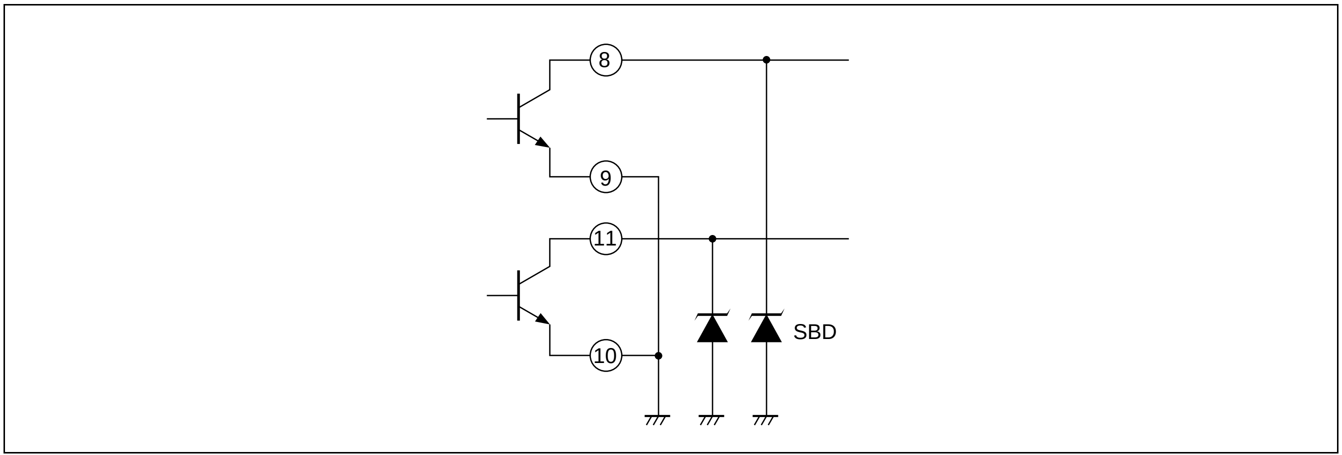


6. Example Protection Circuit for Output Transistor

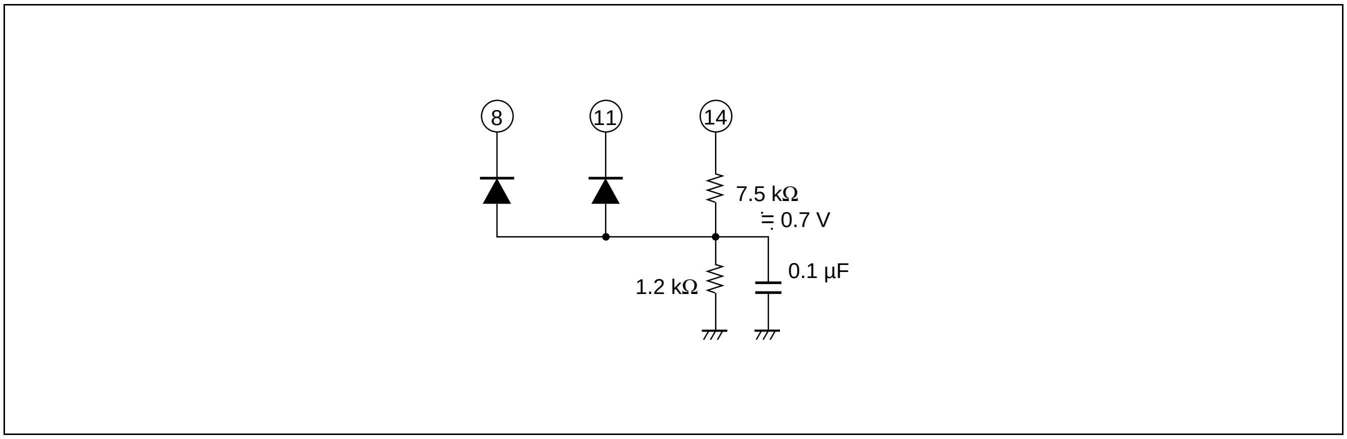
Due to its monolithic IC characteristics, applying a negative voltage greater than the diode voltage (≒ 0.5 V) to the substrate (pin 7) of the MB3759 causes a parasitic effect in the IC which can result in misoperation.

Accordingly, the following measures are required if driving a transformer or similar directly from the output transistor of the IC.

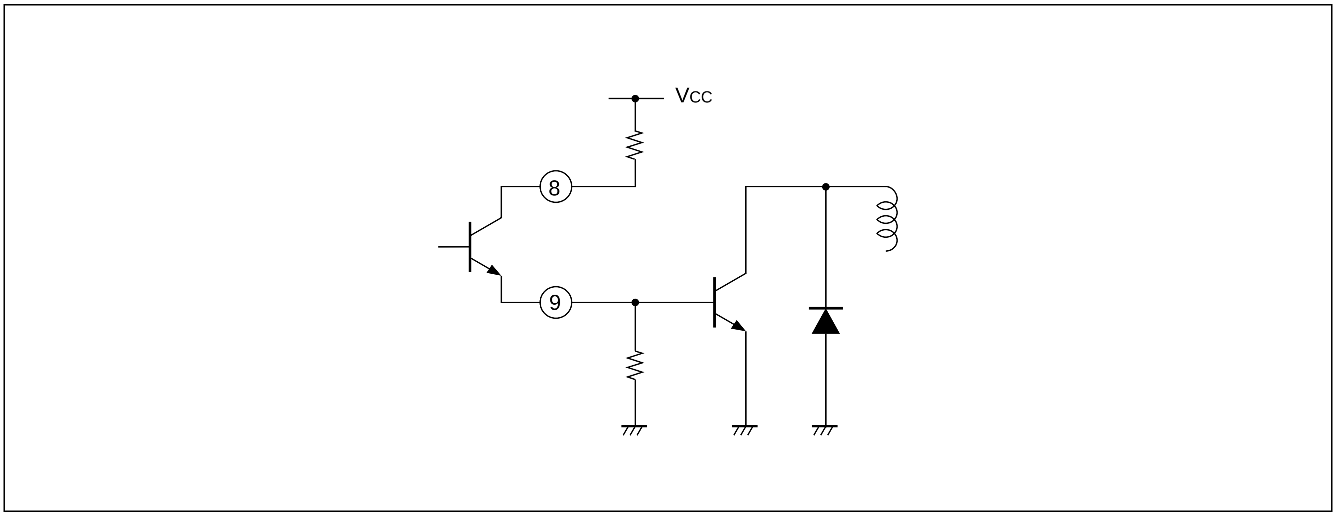
(1) Protect the output transistor from the parasitic effect by using a Schottky barrier diode.



(2) Provide a bias at the anode-side of the diode to clamp the low level side of the transistor.

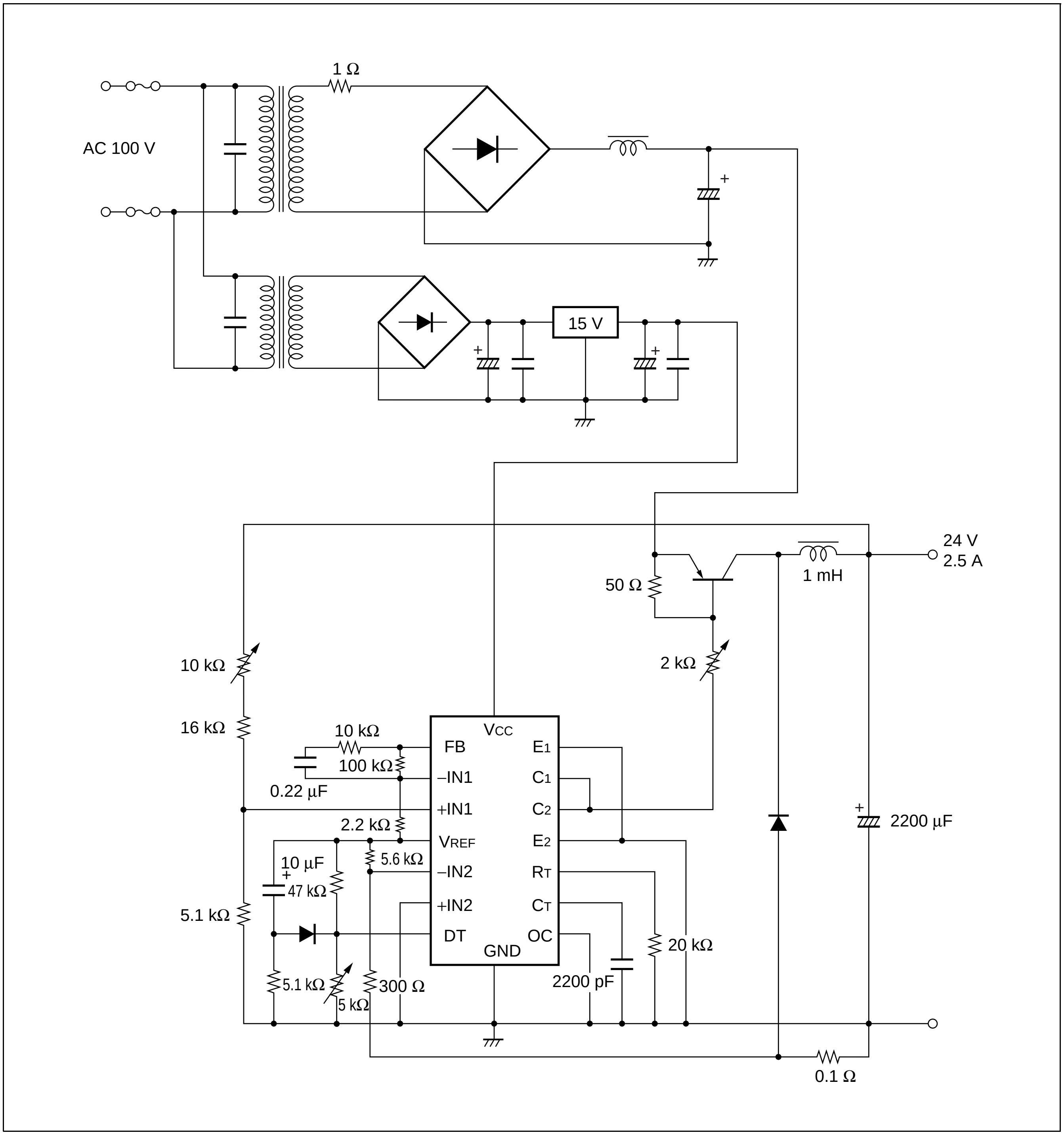


(3) Drive the transformer via a buffer transistor.

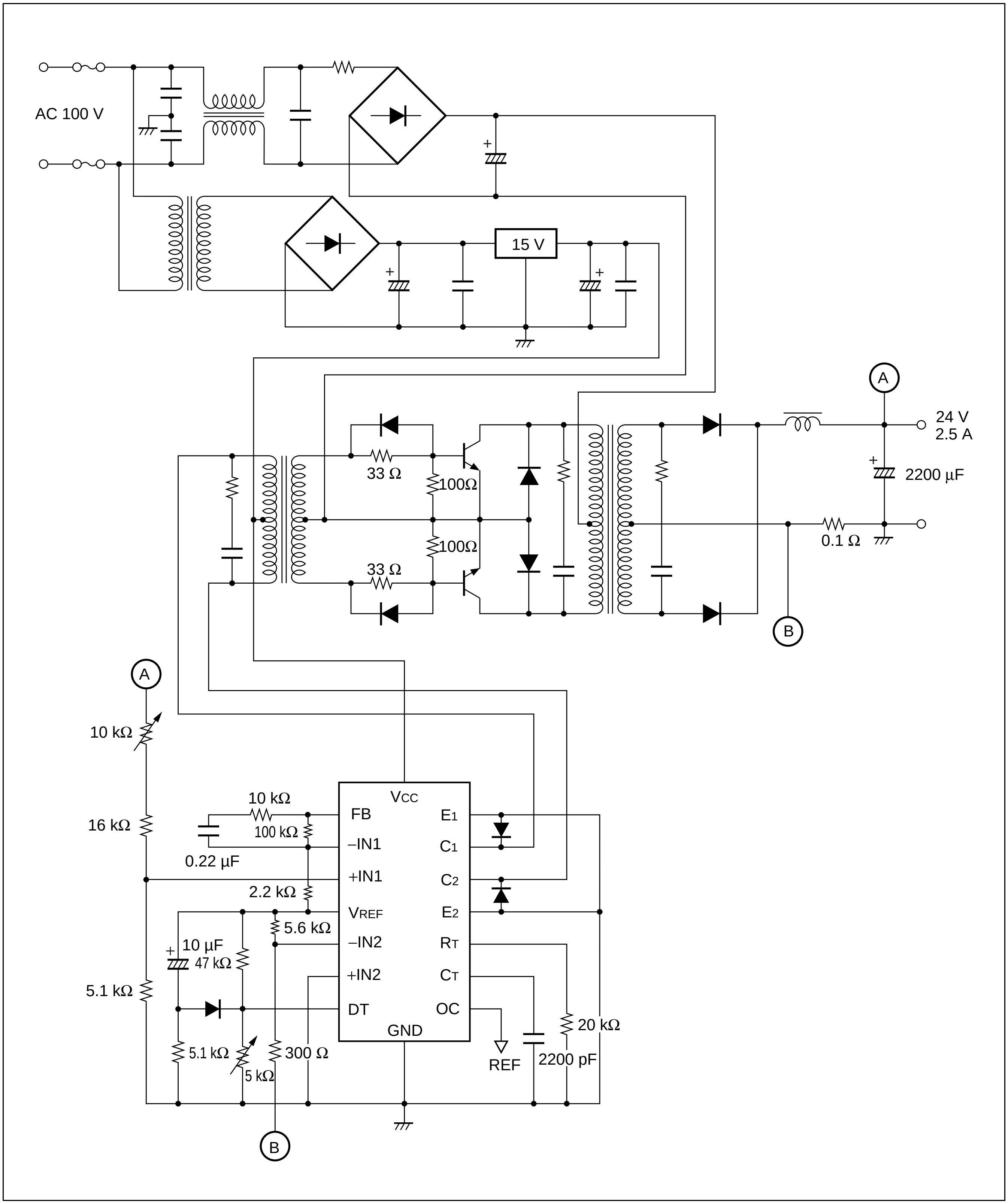


7. Typical Application

(1)Chopper regulator



(2) Inverter regulator



■ NOTES ON USE

- Take account of common impedance when designing the earth line on a printed wiring board.

- Take measures against static electricity.
  - For semiconductors, use antistatic or conductive containers.
  - When storing or carrying a printed circuit board after chip mounting, put it in a conductive bag or container.
  - The work table, tools and measuring instruments must be grounded.
  - The worker must put on a grounding device containing 250 kΩ to 1 MΩ resistors in series.

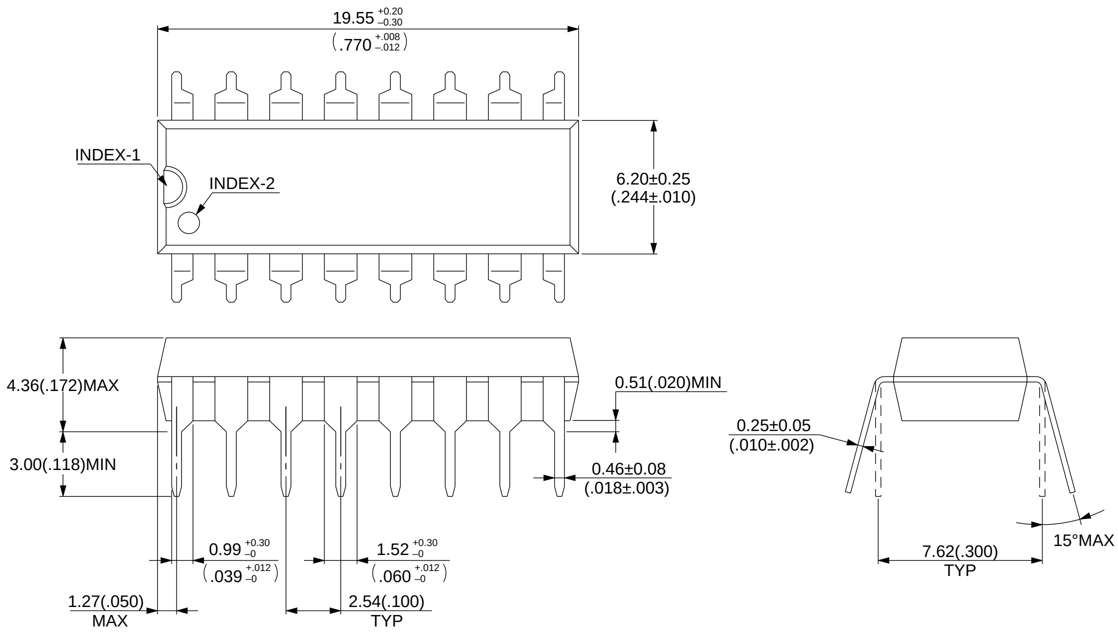
- Do not apply a negative voltage
  - Applying a negative voltage of –0.3 V or less to an LSI may generate a parasitic transistor, resulting in malfunction.

■ ORDERING INFORMATION

Part number	Package	Remarks
MB3759P	16-pin plastic DIP (DIP-16P-M04)	
MB3759PF	16-pin plastic SOP (FPT-16P-M06)	

■ PACKAGE DIMENSIONS

16-pin plastic DIP
(DIP-16P-M04)



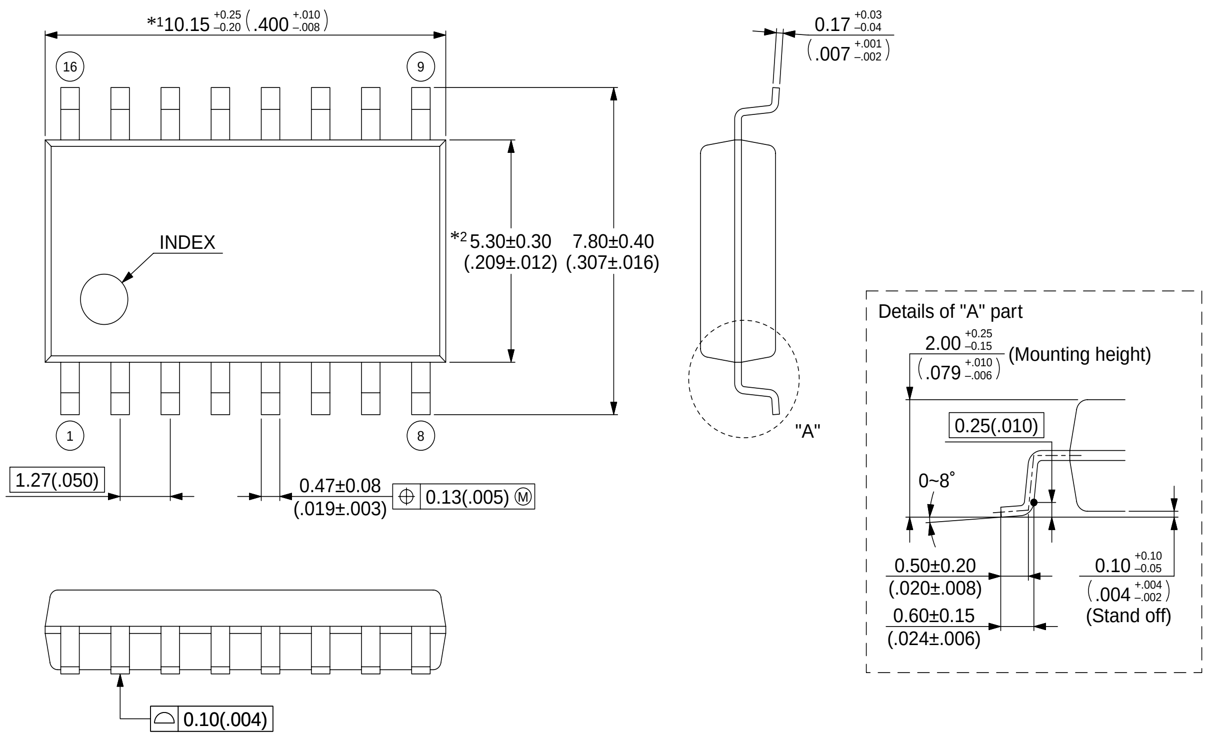
Dimensions in mm (inches) .
Note : The values in parentheses are reference values.

(Continued)

(Continued)

16-pin plastic SOP
(FPT-16P-M06)

Note 1) *1 : These dimensions include resin protrusion.
Note 2) *2 : These dimensions do not include resin protrusion.
Note 3) Pins width and pins thickness include plating thickness.
Note 4) Pins width do not include tie bar cutting remainder.



Dimensions in mm (inches) .
Note : The values in parentheses are reference values.

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