FUJITSU SEMICONDUCTOR
DATA SHEET

DS04-27209-1E

ASSP

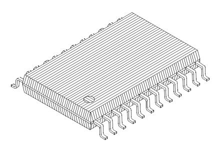
SWITCHING REGULATOR CONTROLLER

MB3788

■ DESCRIPTION

The MB3788 is a dual-channel PWM-type switching regulator controller; it incorporates a reference voltage.
The MB3788 has a PWM circuit and an output circuit as well as a reference voltage power supply with a voltage accuracy of ±1%. The maximum operating frequency is 1 MHz. It is designed for a voltage-drop output switching regulator suitable for a logic power supply or speed control of a DC motor.
The MB3788 is compatible with all master ICs producing triangular waves, sawtooth waves and sine waves with an amplitude of 1.3 to 1.9 V.
It can be used in high-performance portable equipment such as a video camcorder or notebook personal computer (word processor).

24-PIN PLASTIC SSOP



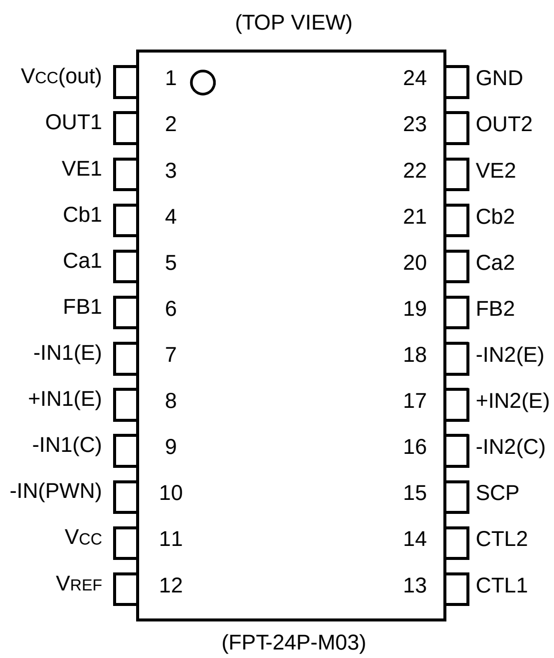
(FPT-24P-M03)

This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields. However, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit.

■ FEATURES

- Wide operating power supply voltage range: 3.6 to 18 V
- Low power dissipation
- Operating: 1.9 mA (standard)
  Standby: 10 µA max.
- High-frequency operation: 100 kHz to 1 MHz
- On-chip timer and latch-type short-circuit detection circuit
- Wide error amplifier input voltage range: -0.2 V to V_{CC} - 1.8 V
- On-chip high-accuracy reference voltage circuit: 2.50 V ±1%
- Output circuit
  PNP transistor drive output pin: Push-pull type
  ON/OFF current values set independently
- On-chip standby function and output control function
- High-density packaging: SSOP-24P

■ PIN ASSIGNMENT



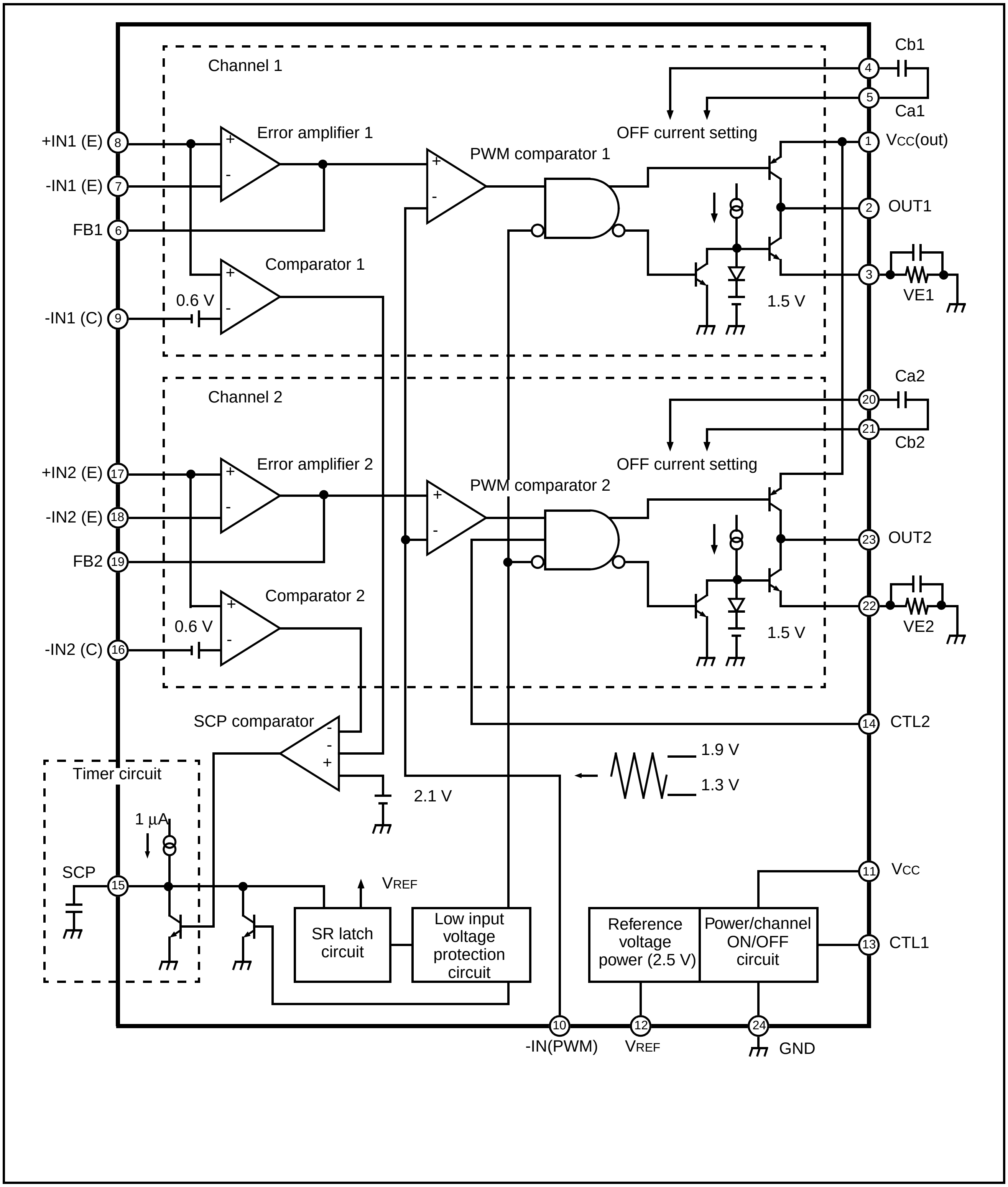
■ PIN DESCRIPTION

Pin No.		Pin name	I/O	Descriptions
Channel 1	2	OUT1	O	Channel 1 push-pull type output
	3	VE1	I	Channel 1 output current setting
	4	Ca1	—	Channel 1 output transistor OFF current setting: Output transistor OFF The current is set by connecting a capacitor between pins Ca1 and Cb1.
	5	Cb1	—	
	6	FB1	O	Channel 1 error amplifier output
	7	-IN1(E)	I	Channel 1 error amplifier inversion input
	8	+IN1(E)		Channel 1 error amplifier non-inversion input
	9	-IN1(C)	I	Channel 1 comparator inversion input
Channel 2	16	-IN2(C)	I	Channel 2 comparator inversion input
	17	+IN2(E)	I	Channel 2 error amplifier non-inversion input
	18	-IN2(E)	I	Channel 2 error amplifier inversion input
	19	FB2	O	Channel 2 error amplifier output
	20	Ca2	—	Channel 2 output transistor OFF current setting: Output transistor OFF The current is set by connecting a capacitor between pins Ca2 and Cb2.
	21	Cb2	—	
	22	VE2	I	Channel 2 output current setting
	23	OUT2	O	Channel 2 push-pull type output
Control circuit	13	CTL1	I	Power and channel 1 control pin H level: Power and channel 1 operating L level: Standby
	14	CTL2	I	Channel 2 control pin When CTL1 pin = H level, H level: Channel 2 operating L level: Channel 2 OFF
	15	SCP	—	Short-circuit protection circuit capacitor connection
Power circuit	1	$V_{CC}2$	—	Output circuit power pin
	10	-IN(PWM)	I	Master oscillating waveform input
	11	$V_{CC}1$	—	Reference power and control circuit power
	12	V_{REF}	O	Reference voltage output
	24	GND	—	Ground

Note: The alphabetic characters in parenthesis above indicate the following input pins.
(C): Comparator
(E): Error amplifier

MB3788

■ BLOCK DIAGRAM



■ FUNCTIONAL DESCRIPTION

1. Major Functions

(1) Reference voltage power circuit

The reference voltage power supply produces a reference voltage (≈ 2.50 V) which is temperature-compensated by the voltage supplied from the power pin (pin 11); it is used as the IC internal circuit operating power supply.
The reference voltage can also be output externally at 1 mA from V_{REF} pin (pin12).

(2) Error amplifier

The error amplifier detects the switching regulator output voltage and outputs a PWM control signal. It has a wide in-phase input voltage range of -0.2 V to V_{CC} - 1.8 V to make setting from an external power supply easy.

Connecting the output pin and inversion input pin of the error amplifier through a feedback resistor and capacitor allows setting of any loop gain to provide stable phase compensation.

(3) PWM comparator

The PWM comparator controls the output pulse ON time according to the input voltage.

The voltage input to the -IN pin (PWM) turns the output transistor on when it is lower than the output voltage of the error amplifier.

(4) Output circuit

The output circuit is configured in a push-pull form and uses a PNP transistor drive system to drive a transistor of up to 30 mA. (See *How to Set Output Current.*)

2. Channel Control Function

Channels can be set ON/OFF by combining the voltage levels at pin CTL1 (pin 13) and pin CTL2 (pin 14).

Channel ON/OFF Setting Conditions

Voltage level at CTL pin		Channel ON/OFF status		
CTL1	**CTL2**	**Power circuit**	**Channel 1**	**Channel**
L	×	Stand by state*		
H	H	ON		ON
	L			OFF

*The power current in the standby state is 10 µA max.

3. Protection Functions

(1) Timer and latch-type short-circuit protection circuit

The SCP comparator detects the output voltage levels of two comparators to detect an output short circuit. If the output voltage of one comparator increases to 2.1 V, the transistor of the timer circuit is turned off and the short circuit protection capacitor connected externally to the SCP pin (pin 15) starts charging.

The latch circuit turns off the output transistor and simultaneously clears the duty cycle to 0 when the output voltage level of the comparator does not return to the normal voltage level until the capacitor voltage rises to the base-emitter junction voltage VBE (≈ 0.65 V) of the transistor. (See *How to Set Time Constant for Timer & Latch-Type Short-Circuit Protection Circuit.*)

When the protection circuit operates, recycle the power to reset the circuit.

(2) Low input voltage malfunction fail-safe circuit

A transient at power-on, or an instantaneous supply voltage drop can cause a control IC malfunction, which may damage the system. The low input voltage malfunction fail-safe circuit detects the internal reference voltage level based on the supply voltage level, resets the latch circuit, turns off the output transistor, clears the duty cycle to 0 and holds the SCP pin (pin 15) at Low level. All circuits are recovered when the supply voltage is greater than the threshold voltage of the fail-safe circuit.

■ ABSOLUTE MAXIMUM RATINGS

(T_A = +25°C)

Parameter	Symbol	Conditions	Ratings	Unit
Supply voltage	V_{CC}	—	20	V
Control input voltage	V_{ICTL}	—	20	V
Allowable loss	P_D	Ta ≤ +25°C	500*	mW
Operating ambient temperature	T_{OP}	—	-30 to +85	°C
Storage temprature	T_{stg}	—	-55 to +125	°C

* Value obtained when mounted on 4 cm × 4 cm double-sided epoxy substrate

■ RECOMMENDED OPERATING CONDITIONS

(T_A = +25°C)

Parameter	Symbol	Conditions	Values			Unit
			Min.	Typical	Max.	
Supply voltage	V_{CC}	—	3.6	6.0	18	V
Reference voltage output curren	I_{OR}	—	-1	—	0	mA
Error amplifier input voltage	V_I	—	-0.2	—	V_{CC} - 1.8	V
Error amplifier input voltage	V_I	—	-0.2	—	V_{CC}	V
Control input voltage	V_{ICTL}	—	-0.2	—	18	V
Output current	I_O	—	3.0	—	30	mA
Operating frequency	f_{osc}	—	100	300	1000	kHz
Operating ambient temperature	T_{op}	—	-30	25	85	°C

■ ELECTICAL CHARACTERISTICS

(V_{CC} =6V, T_A = +25°C)

Parameter		Symbol	Conditions	Value			Unit
				Min.	Typical	Max.	
Reference voltage	Reference voltage	V_{REF}	I_{OR} = -1 mA	2.475	2.500	2.525	V
	Output voltage temperature variation	$\Delta V_{REF}/V_{REF}$	T_A = -30° to +85°C	-2	±0.2	2	%
	Input stability	Line	V_{CC} = 3.6 V to 18 V	—	2	10	mV
	Load stability	Load	I_{OR} = -0.1 mA to 1 mA	—	3	10	mV
	Short-circuit output current	I_{OS}	V_{REF} = 2 V	-20	-8	-3	mA
Low voltage malfunction fail-safe circuit	Threshold voltage	V_{tH}	—	—	2.65	—	V
		V_{tL}	—	—	2.45	—	V
	Hysteresis width	V_{HYS}	—	80	200	—	mV
	Reset voltage	V_R	—	1.5	1.9	—	V
Short-circuit detection comparator	Input offset voltage	V_{IO}	—	0.58	0.65	0.72	V
	Input bias current	I_{IB}	V_I = 0 V	-200	-100	—	nA
	In-phase input voltage range	V_{ICM}	—	-0.2	—	V_{CC}-1.8	V
Short-circuit detector	Threshold voltage	V_{tPC}	—	0.60	0.65	0.70	V
	Input standby voltage	V_{STB}	—	—	50	100	mV
	Input latch voltage	V_I	—	—	50	100	mV
	Input source current	I_{Ibpc}	—	-1.4	-1.0	-0.6	µA
Error amplifier	Input offset voltage	V_{IO}	V_{FB} = 1.6 V	-10	—	10	mV
	Input offset current	I_{IO}	V_{FB} = 1.6 V	-100	—	100	nA
	Input bias current	I_{IB}	V_{FB} = 1.6 V	-200	-60	—	nA
	In-phase input voltage range	V_{ICM}	—	-0.2	—	V_{CC}-1.8	V
	Voltage gain	A_V	—	60	100	—	dB
	Frequency bandwidth	BW	A_V = 0 dB	—	800	—	kHz
	In-phase signal rejection ratio	CMRR	—	60	80	—	dB
	Maximum output voltage width	V_{OM+}	—	V_{REF}-0.3	2.4	—	V
		V_{OM-}	—	—	0.05	0.5	V
	Output sink current	I_{OM+}	V_{FB} = 1.6 V	—	120	—	µA
	Output source current	I_{OM-}	V_{FB} = 1.6 V	—	-2	—	mA

Parameter		Symbol	Conditions	Values			Unit
				Min.	Typical	Max.	
PWM comparator	Threshold voltage	V_{t0}	Duty cycle = 0 %	1.05	1.3	—	V
		V_{t100}	Duty cycle = 100 %	—	1.9	2.25	V
	Input sink current	I_{IM+}	—	—	120	—	µA
	Input source current	I_{IM-}	—	—	-2	—	mA
	Input bias current	I_{IB}	V_I = 0 V	-1.0	-0.5	—	µA
Control	Threshold voltage	V_{th}	—	0.7	1.4	2.1	V
	Input current	I_{IH}	V_{CTL} = 5 V	—	100	200	µA
		I_{IL}	V_{CTL} = 0 V	-10	—	10	µA
Output	Source current	I_O	—	—	-40	—	mA
	Sink curren	I_O	R_B = 50 Ω	18	30	42	mA
	Output leak current	I_{LO}	V_O = 18 V	—	—	20	µA
All devices	Standby current	I_{CCO}	—	—	0	10	µA
	Power current at output OFF	I_{CC}	—	—	1.9	2.7	mA

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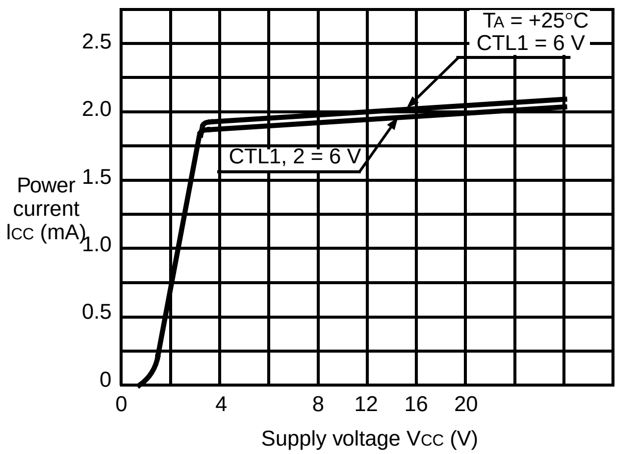
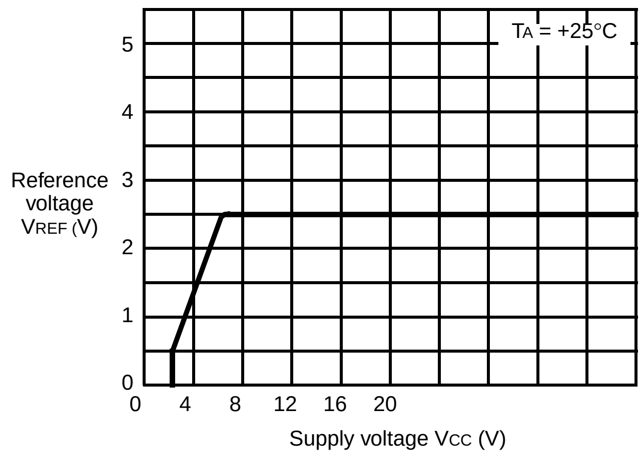
■ STANDARD CHARACTERISTIC CURVES

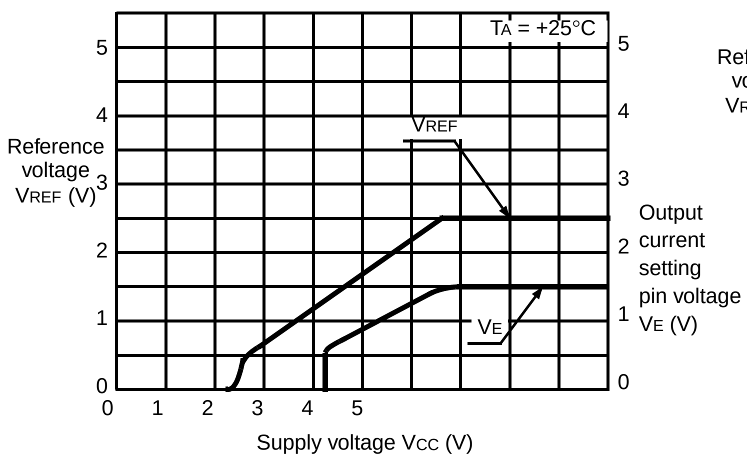
1. Power current - supply voltage characteristic



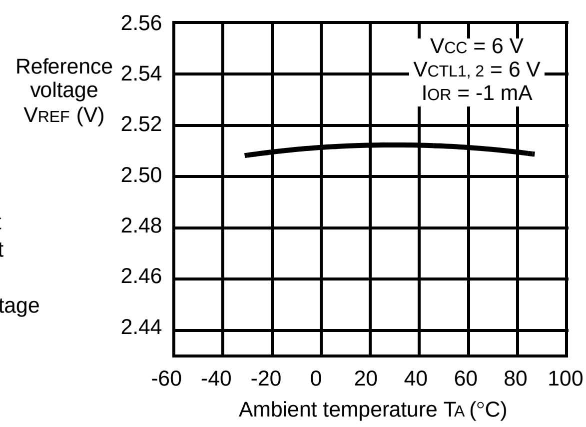
2. Reference voltage - supply voltage characteristic



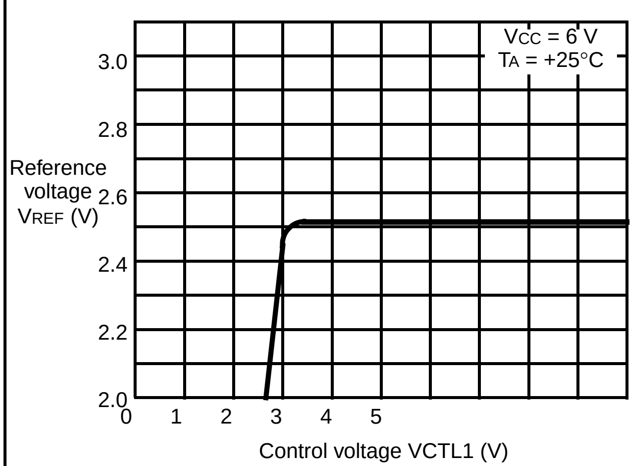
3.Reference voltage, output current setting pin voltage - supply voltage characteristic



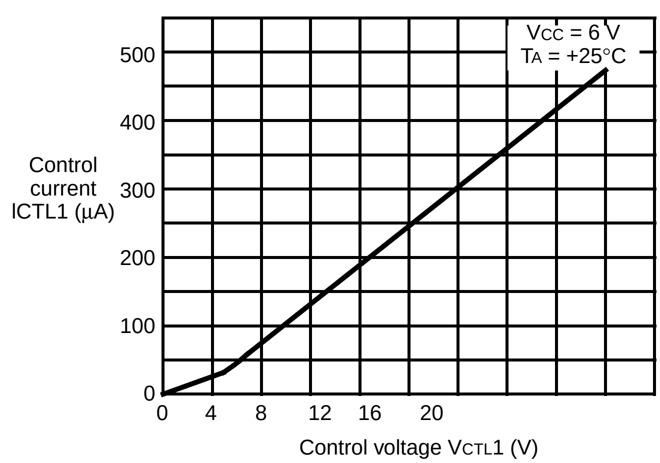
4. Reference voltage - ambient temperature characteristic



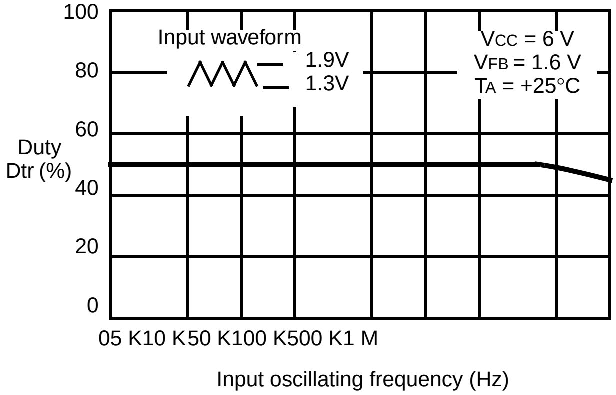
5. Reference voltage - control voltage characteristic



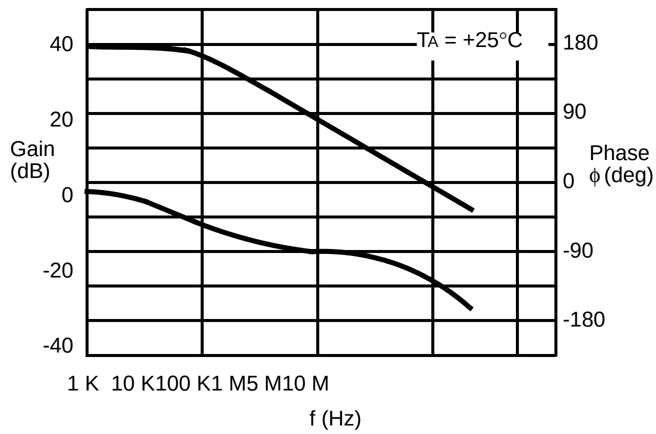
6. Control current - control voltage characteristic



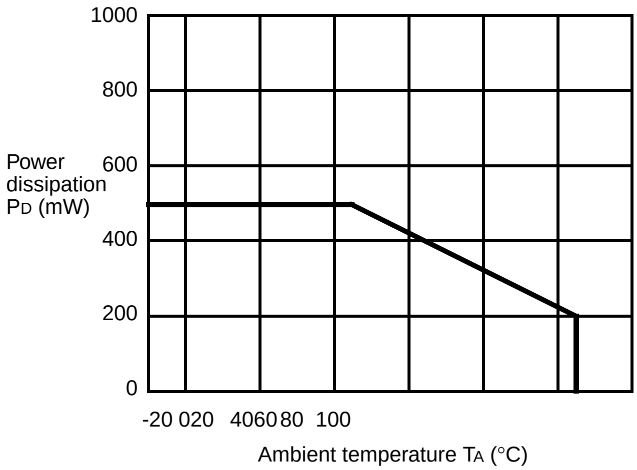
7. Duty - input oscillating frequency characteristic



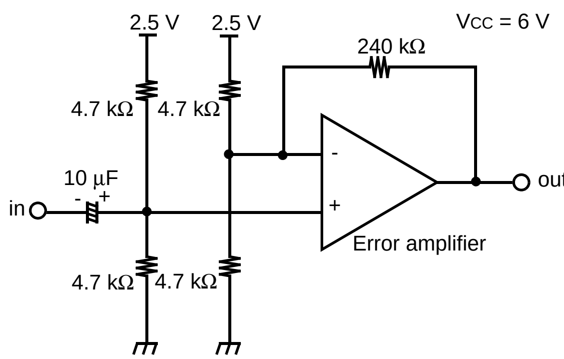
8.Gain - frequency characteristic and phase - frequency characteristic



9. Power dissipation - ambient temperature characteristic



Circuit for measuring gain - frequency characteristic and phase - frequency characteristic



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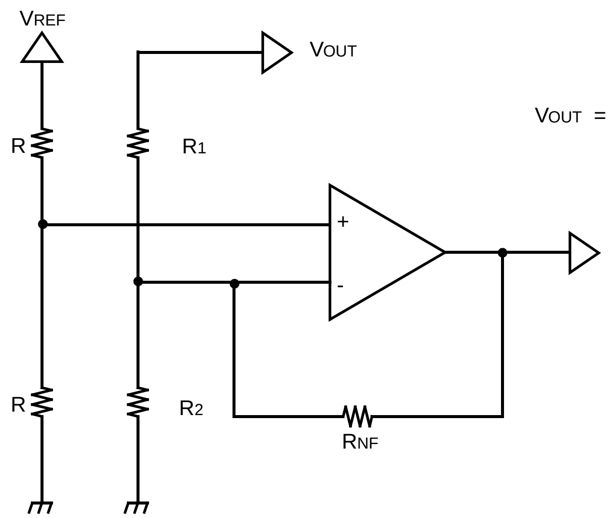
■ HOW TO SET OUTPUT VOLTAGE



$$V_{OUT} = \frac{V_{REF}}{2 \times R_2}(R_1 + R_2)$$

Note: Set the output voltage in the positive range ($V_{OUT} > 0$).

■ HOW TO SET OUTPUT CURRENT

The output circuit is configured in a push-pull type as shown in Figure 1. The ON current value of the output current waveform shown in Figure 2 is a constant current and the OFF value set by RE is set by a time constant. Each output current can be calculated from the following expression:

- ON current = 1.5/R_E (A) (Output current setting pin voltage: $V_E \approx 1.5$ V)
- The OFF current time constant is proportional to the value of C_B.

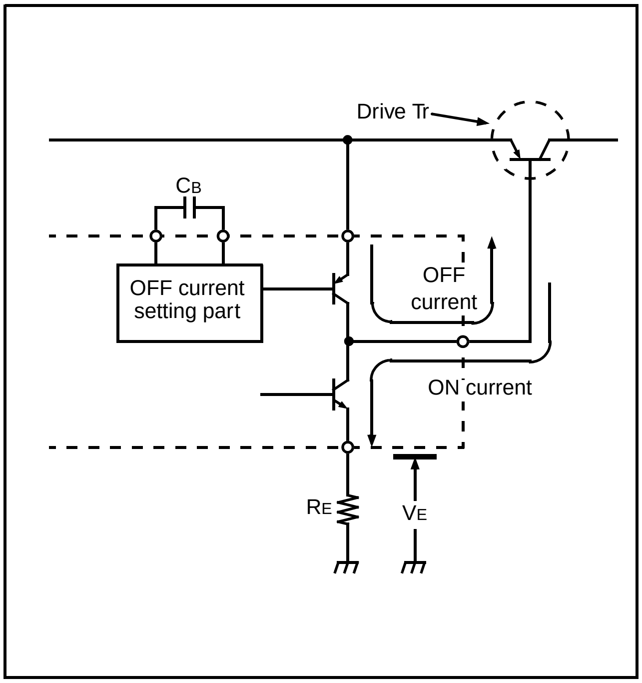


Fig.1 Output Circuit Diagram

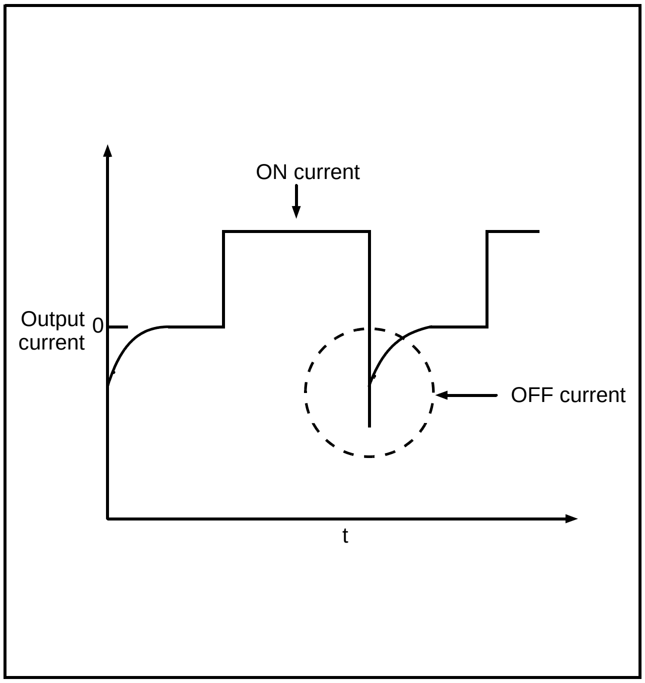


Fig.2 Output Current Waveform

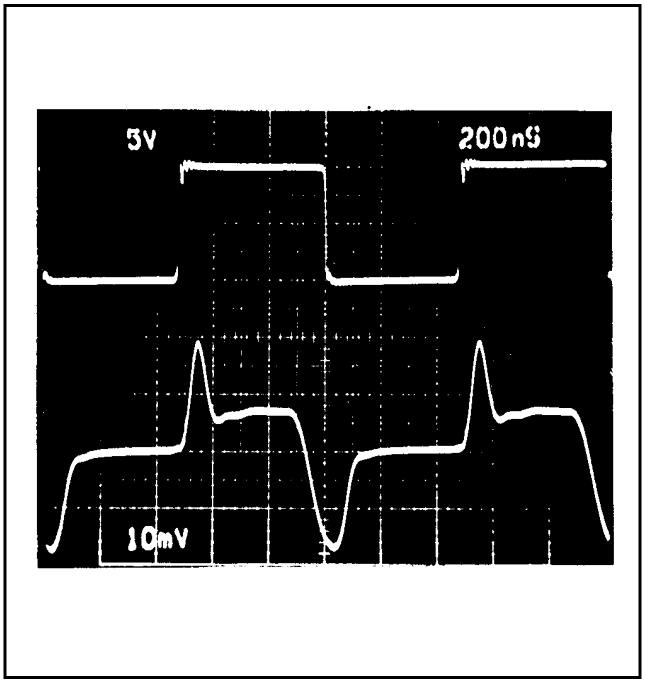


Fig.3 Output Pin Voltage and Current Waveforms (Channel 1)

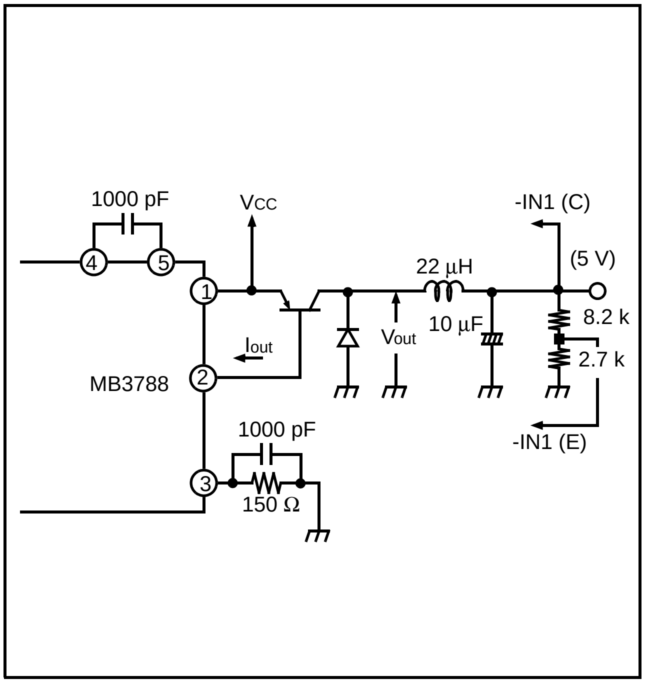


Fig.4 Measurement Circuit Diagram

■ HOW TO SET TIME CONSTANT FOR TIMER & LATCH-TYPE SHORT-CIRCUIT PROTECTION CIRCUIT

If the load conditions of the switching regulator are stable, the outputs of comparators 1 and 2 do not change, so the SP comparator outputs a High level. At this time, the SCP pin (pin 15) is held at about 50 mV.

If the load conditions change suddenly due to a load short-circuit, for example, the output voltage of the comparator of the channel becomes a High-level signal (more than 2.1 V). Then, the SVP comparator outputs a Low level and transistor Q1 is turned off. The short-circuit protection capacitor C_{PE} externally connected to the SCP pin starts to charge.

$V_{PE} = 50\text{ mV} + t_{PE} \times 10^{-6}/C_{PE}$

$0.65 = 50\text{ mV} + t_{PE} \times 10^{-6}/C_{PE}$

$C_{PE} = t_{PE}/0.6\text{ (s)}$

Once the capacitor C_{PE} is charged to about 0.65 V, the SR latch is set and the output drive transistor is turned off. At this time, the duty cycle is made low and the output voltage of the SCP pin (pin 15) is held at Low level. This closes the SR latch input to discharge C_{PE}.

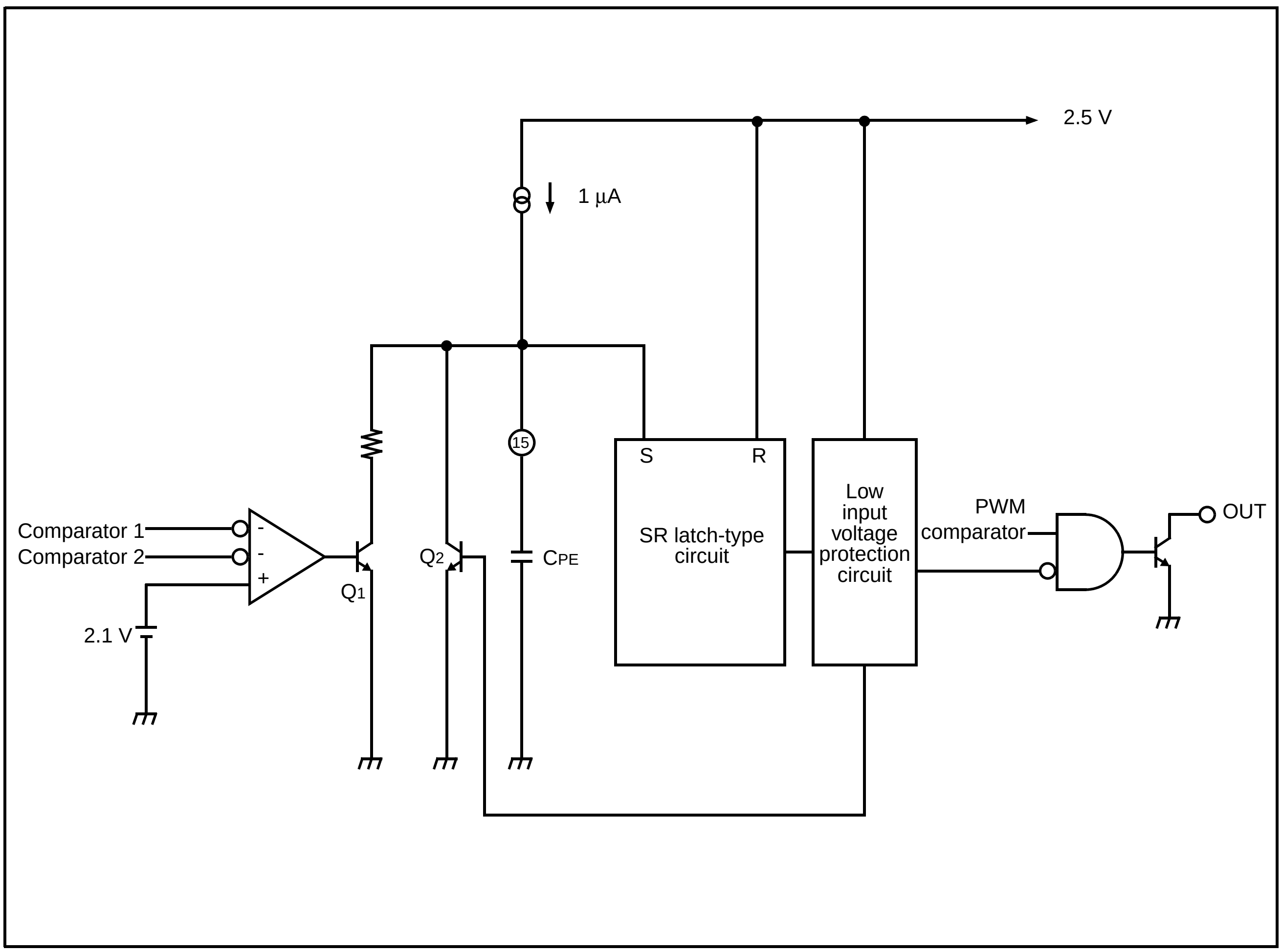


Fig. 5 Latch-Type Short-Circuit Protection Circuit

■ PROCESSING WITHOUT USING SCP PIN

If the timer and latch-type short-circuit protection circuit is not used, connect the SCP pin (pin 15) to GND as close as possible. Also, connect the input pin of each channel comparator to the VCC pin (pin 11).

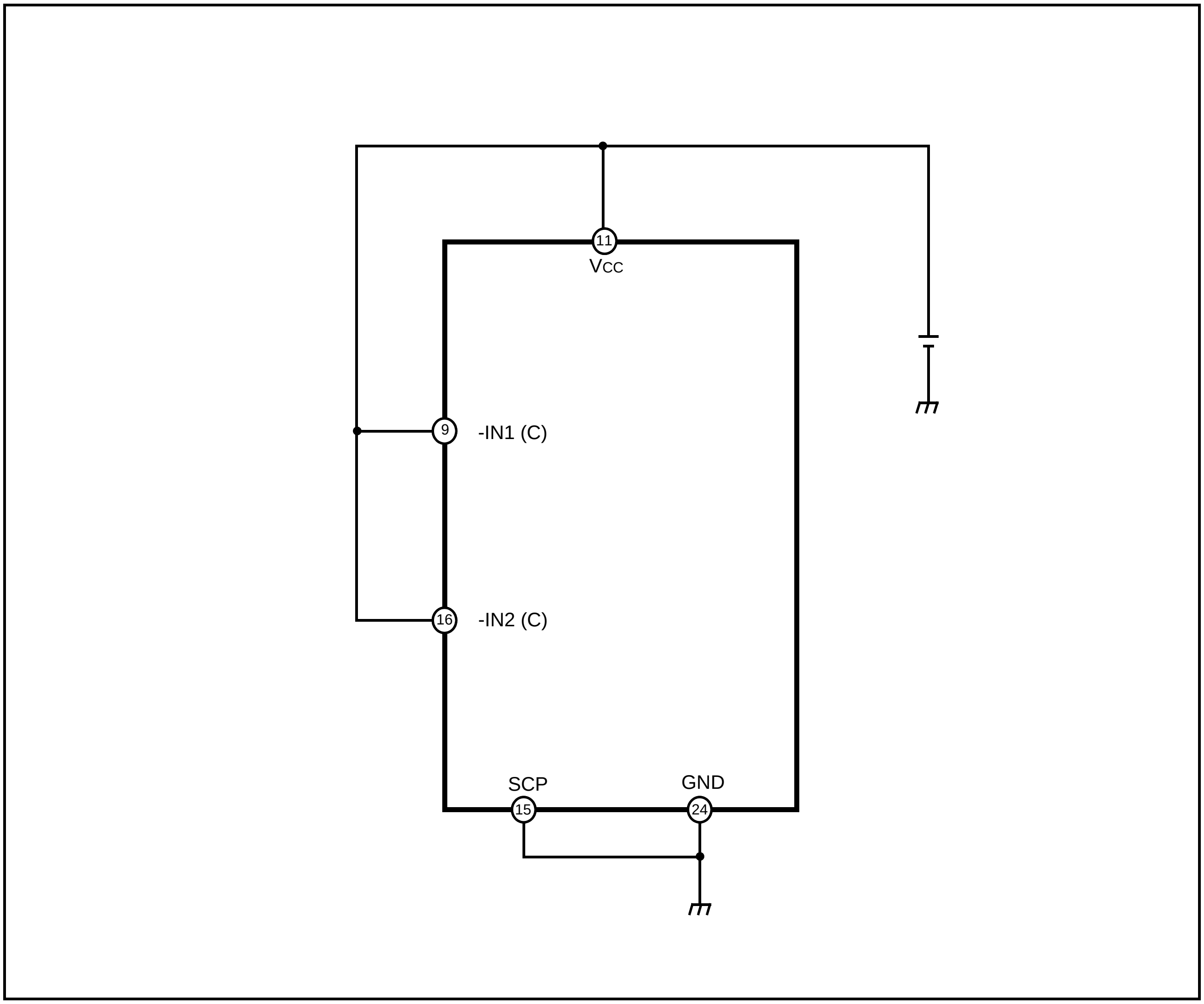


Fig. 6 Processing without using SCP Pin

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■ EQUIVALENT SERIES RESISTANCE OF SMOOTHING CAPACITOR AND STABILITY OF DC/DC CONVERTER

The equivalent series resistance (ESR) of the smoothing capacity in a DC/DC converter has a great effect on the loop phase characteristics.

The ESR causes a small delay at the capacitor with a series resistance of 0 (Figures 8 and 9), thus improving system stability. On the other hand, using a smoothing capacitor with a low ESR reduces system stability. Therefore, attention should be paid to using semiconductor electrolytic capacitors (such as OS capacitors) or tantalum capacitors with a low ESP. (Phase margin reduction by using an OS capacitor is explained on the next page.)

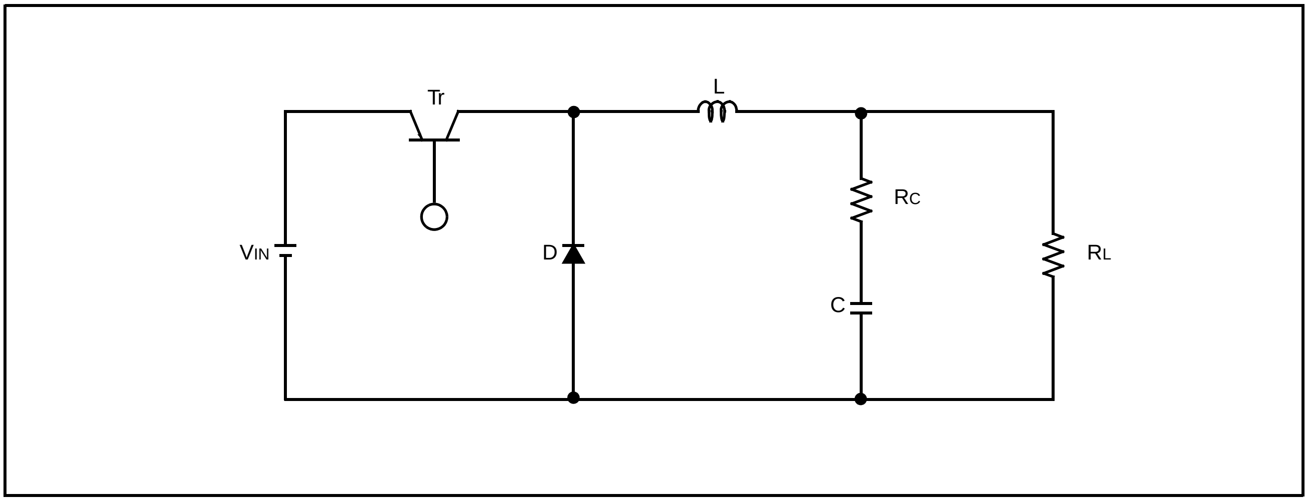


Fig. 7 Basic Voltage-Drop Type DC/DC Converter Circuit

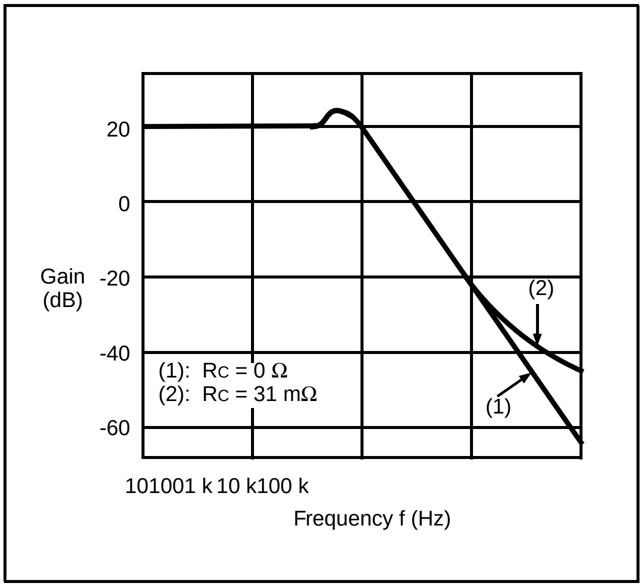


Fig.8 Gain - Frequency Characteristic

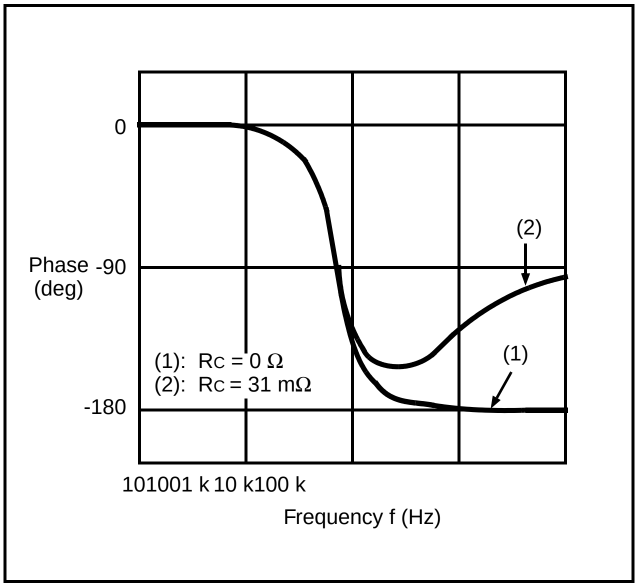


Fig.9 Phase - Frequency Charecteristic

(Reference Data)

The phase margin is halved by changing the smoothing capacitor from an aluminum electrolytic capacitor (Rc = 1.0 Ω) to a semiconductor electrolytic capacitor (OS capacitor: Rc = 0.2 Ω) with a low ESR (Figures 11 and 12).

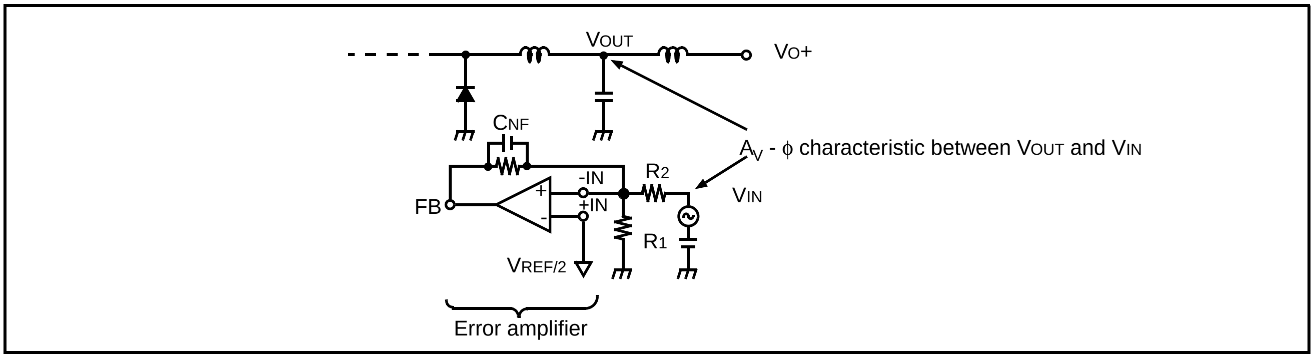


Fig. 10 DC/DC Converter A_V - ϕ Characteristic Measurement Diagram

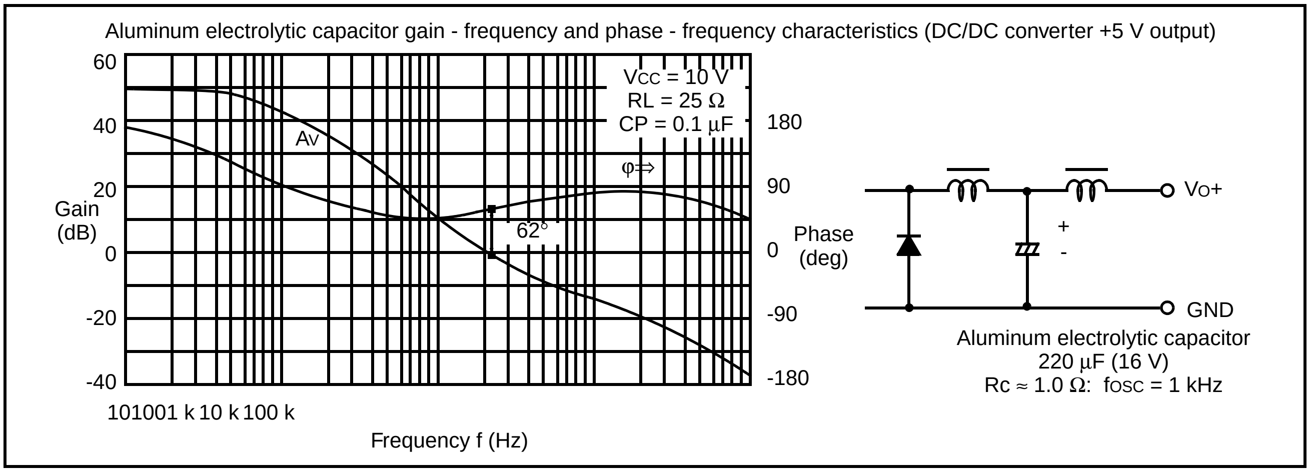


Fig. 11 Gain - Frequency Characteristic

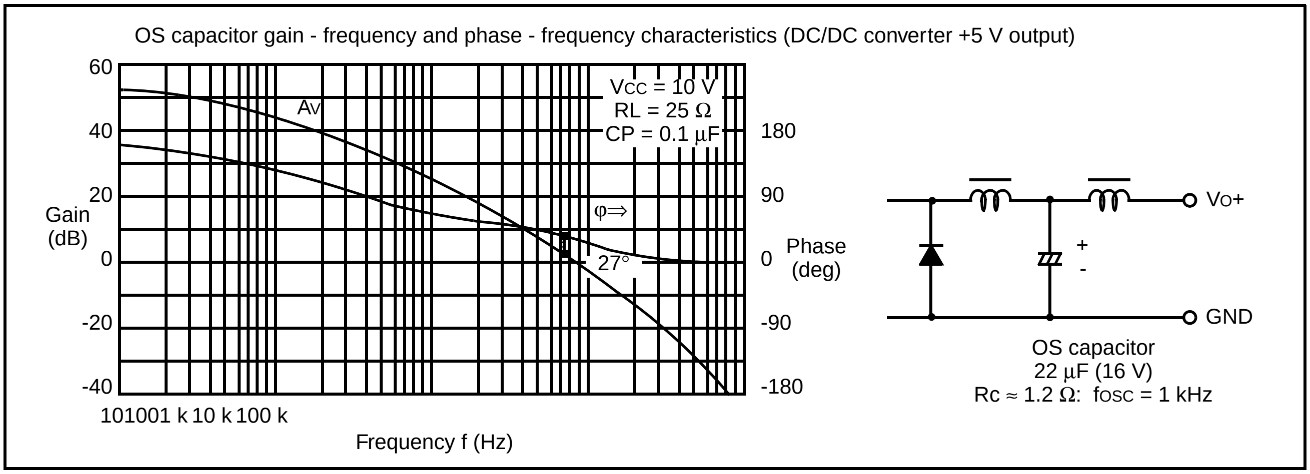
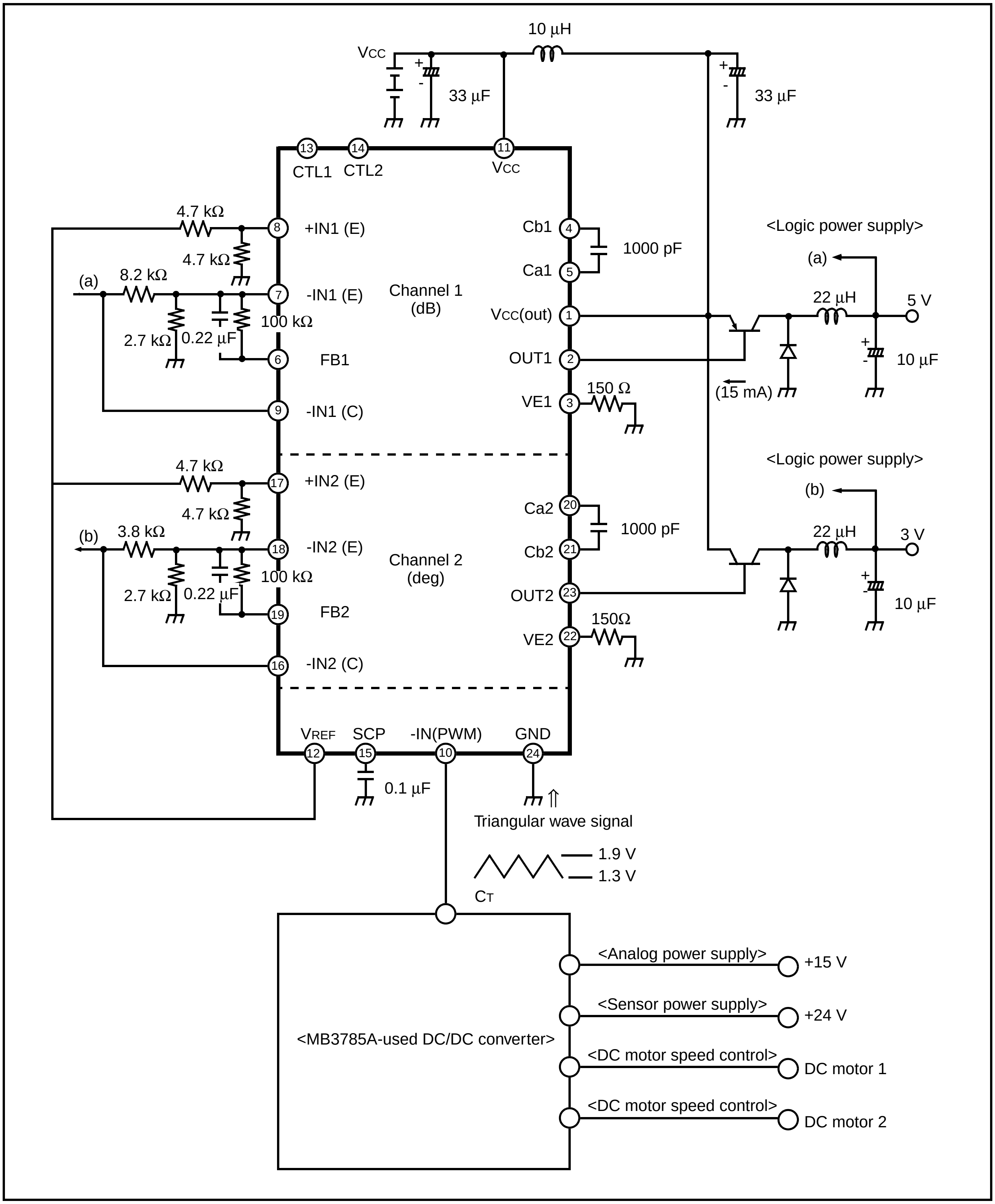


Fig.12 Phase - Frequency Characteristic Curves

■ APPLICATION CIRCUIT



■ PRECAUTIONS

1. Do not apply any voltage greater than the maximum rating, or the LSI may be damaged.
2. Use the MB3788 under the recommended operating conditions.
   If a voltage greater than the maximum voltage is applied, the electrical characteristics are not guaranteed; if a voltage smaller than the minimum voltage is applied, the LSI operation will become unstable.
3. To ground the PC board, use the thickest cable possible because high frequencies are used which can easily produce high-frequency noise.
4. Connecting unused channel pin
   For unused channels, the output voltage of the comparator for detecting a short-circuit must be fixed at the Low level.
5. Take measures against static electricity.
   - Carry semiconductors in a conductive container or anti-static case.
   - Carry the PC board in a conductive bag or container if it is stored or transported after packaging.
   - Ground the workbench, and all tools and measuring instruments.
   - Workers should be grounded through a resistance of 250 kΩ to 1 MΩ.

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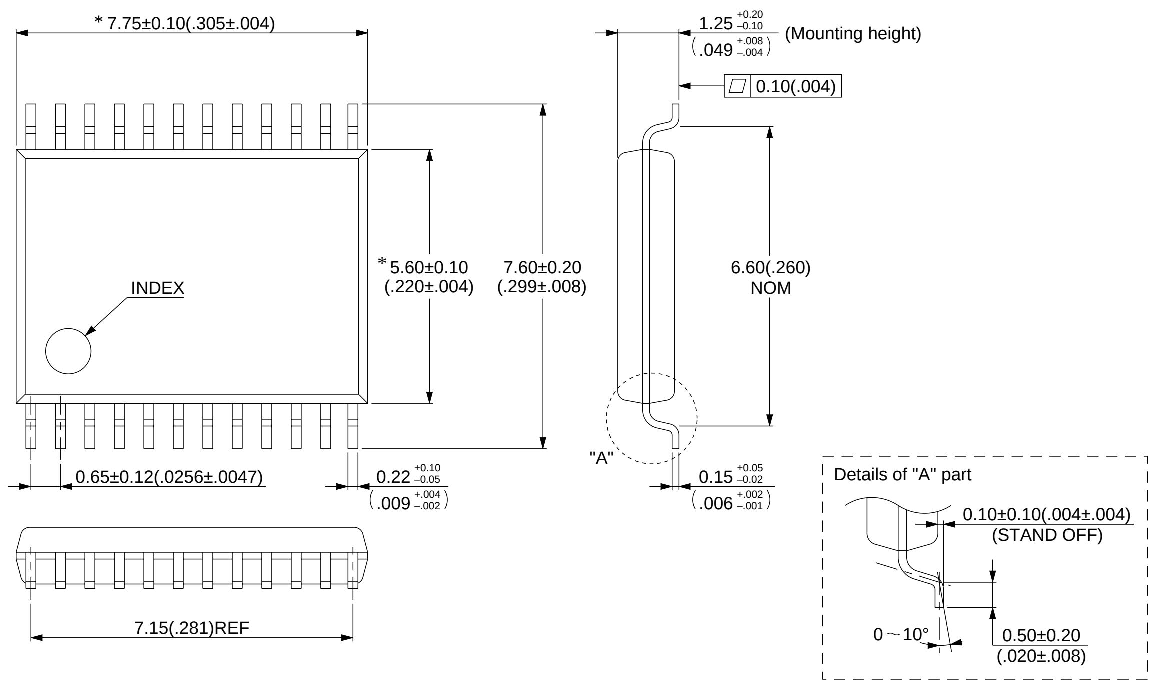
■ PACKAGE DIMENSION

24-pin plastic SSOP
(FPT-24P-M03)



Dimensions in mm (inches).

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