

The S-8351/8352 Series is a CMOS PFM-control step-up switching regulator that mainly consists of a reference voltage source, an oscillator, and a comparator. The PFM controller allows the duty ratio to be automatically switched according to the load (light load: 50%, high output current: 75%), enabling products with a low ripple over a wide range, high efficiency, and high output current (product types A, B, and D). Products with a fixed duty ratio of 75% are also available (product type C).

With the S-8351 Series, a step-up switching regulator can be configured by using an external coil, capacitor, and diode. The built-in MOS FET is turned off by a protection circuit when the voltage at the CONT pin exceeds the limit to prevent it from being damaged. This feature, along with the mini package and low current consumption, makes the S-8351 Series ideal for applications such as the power supply unit of portable equipment.

The S-8352 Series, which features an external transistor, is suitable for applications requiring a high output current.

■ Features

- Low voltage operation: Startup at 0.9 V min. ($I_{OUT} = 1$ mA) guaranteed
- Low input current: During maximum operation: 23.2 μ A ($V_{OUT} = 3.3$ V, typ.)
During shutdown: 0.5 μ A (max.)
- Duty ratio: 50/75%, built-in auto-switching-type PFM controller (product types A, B, D)
75%, built-in fixed-type PFM controller (product type C)
- External parts: Coil, capacitor, diode
- Output voltage: Settable to between 2.0 to 6.5 V (product types A, B, C) or 1.5 to 6.5 V (product type D) in 0.1 V steps, accuracy of $\pm 2.4\%$
- Shutdown function (product type A)
- V_{DD}/V_{OUT} separate type (product type D)
- External transistor type available (S-8352 Series)

■ Packages

- SOT-23-3 (package drawing code: MP003-A)
- SOT-23-5 (package drawing code: MP005-A)
- SOT-89-3 (package drawing code: UP003-A)

■ Applications

- Power supply for portable equipment such as digital cameras, electronic notebooks, and PDAs
- Power supply for audio equipment such as portable CD/MD players
- Constant voltage power supply for cameras, video equipment, and communications equipment
- Power supply for microcomputers

■ Applications

1. Function List

Product Name	Control System (Duty Ratio (%))	Switching Frequency (kHz)	Shutdown Function	V_{DD}/V_{OUT} Separate Type	Power MOS FET	Package	Application
S-8351AxxMC	PFM (50/75)	100	Yes	—	Built-in	SOT-23-5	Application requiring shutdown function
S-8351BxxMA	PFM (50/75)	100	—	—	Built-in	SOT-23-3	Application not requiring shutdown function
S-8351CxxMA	PFM (75)	100	—	—	Built-in	SOT-23-3	Application not requiring shutdown function
S-8351CxxUA	PFM (75)	100	—	—	Built-in	SOT-89-3	Application not requiring shutdown function
S-8351DxxMC	PFM (50/75)	100	—	Yes	Built-in	SOT-23-5	Application in which output voltage is adjusted by external resistance
S-8352AxxMC	PFM (50/75)	100	Yes	—	External	SOT-23-5	Application requiring shutdown function
S-8352BxxMA	PFM (50/75)	100	—	—	External	SOT-23-3	Application not requiring shutdown function
S-8352CxxMA	PFM (75)	100	—	—	External	SOT-23-3	Application not requiring shutdown function
S-8352CxxUA	PFM (75)	100	—	—	External	SOT-89-3	Application not requiring shutdown function
S-8352DxxMC	PFM (50/75)	100	—	Yes	External	SOT-23-5	Application in which output voltage is adjusted by external resistance

2. Product Name

S-835 X X XX XX – XXX – T2

IC direction in tape specification

Product name

Package name

MA; SOT-23-3 (without shutdown function)

MC; SOT-23-5 (with shutdown function or V_{DD}/V_{OUT} separate type)

UA; SOT-89-3 (without shutdown function)

Output voltage × 10 (15 for output voltage value 1.5)

Product type

A ; With shutdown function

B ; Automatic duty ratio switching type

C ; Duty ratio fixed type (75%)

D ; V_{DD}/V_{OUT} separate type

Series name

1; Built-in power MOS FET

2; External power MOS FET

3. Product Name List

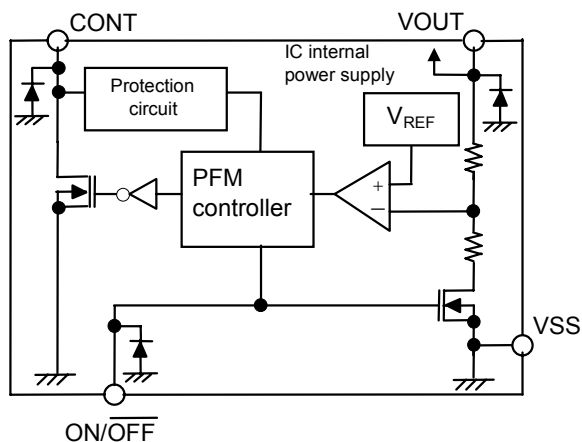
Output Voltage	S-8351AxxMC Series	S-8351BxxMA Series	S-8351CxxMA S-8351CxxUA Series	S-8351DxxMC Series
3.0	S-8351A30MC-J2P-T2	S-8351B30MA-J4P-T2	—	—
3.3	S-8351A33MC-J2S-T2	—	—	—
3.5	S-8351A35MC-J2U-T2	—	—	—
5.0	S-8351A50MC-J3J-T2	—	—	—
5.5	S-8351A55MC-J3O-T2	—	—	—

Output Voltage	S-8352AxxMC Series	S-8352BxxMA Series	S-8352CxxMA S-8352CxxUA Series	S-8352DxxMC Series
2.0	—	—	—	S-8352D20MC-K8F-T2
3.0	S-8352A30MC-K2P-T2	S-8352B30MA-K4P-T2	—	—
5.0	S-8352A50MC-K3J-T2	—	—	—

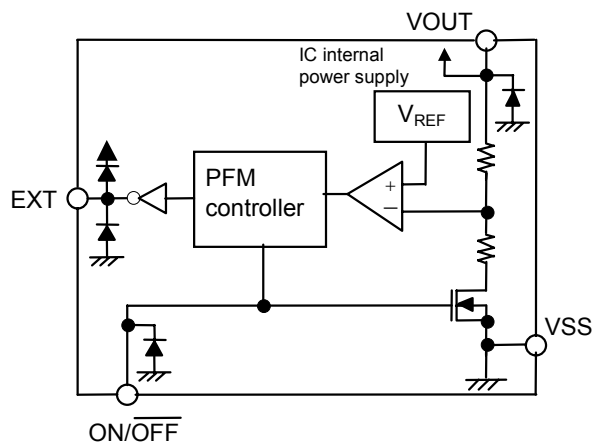
Remark Please consult our sales staff if you require a product with an output voltage other than those specified above.

■ Block Diagrams

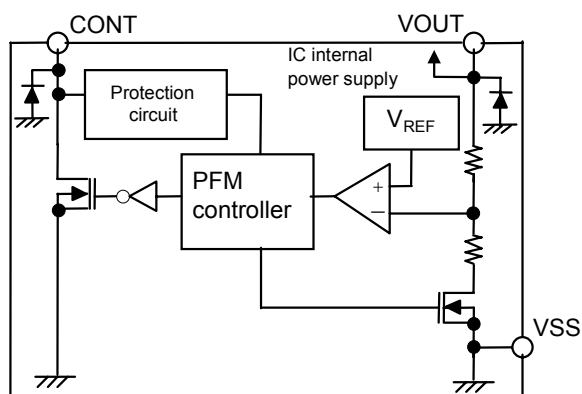
(1) S-8351 Series A type (with shutdown function)



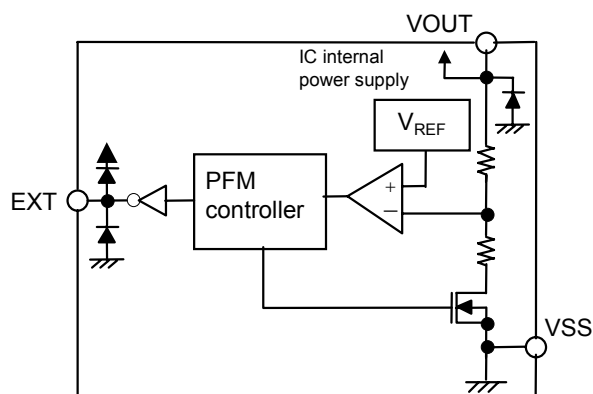
(2) S-8352 Series A type (with shutdown function)



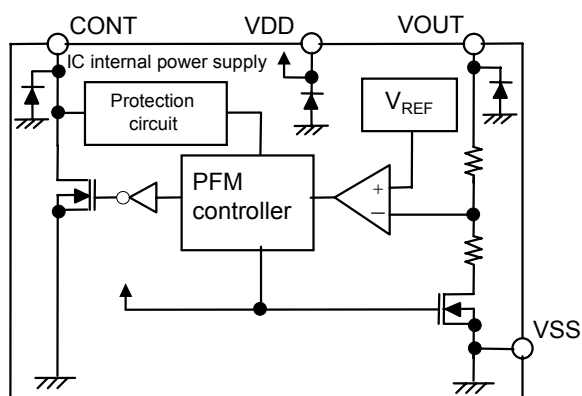
(3) S-8351 Series B, C type (without shutdown function)



(4) S-8352 Series B, C type (without shutdown function)



(5) S-8351 Series D type (V_{DD}/V_{OUT} separate type)



(6) S-8352 Series D type (V_{DD}/V_{OUT} separate type)

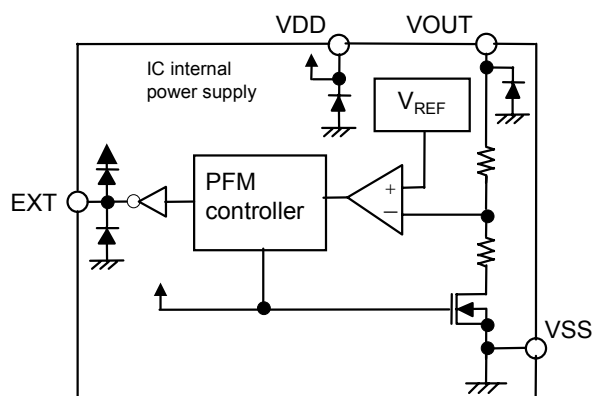


Figure 1. Block Diagrams

Pin Assignment

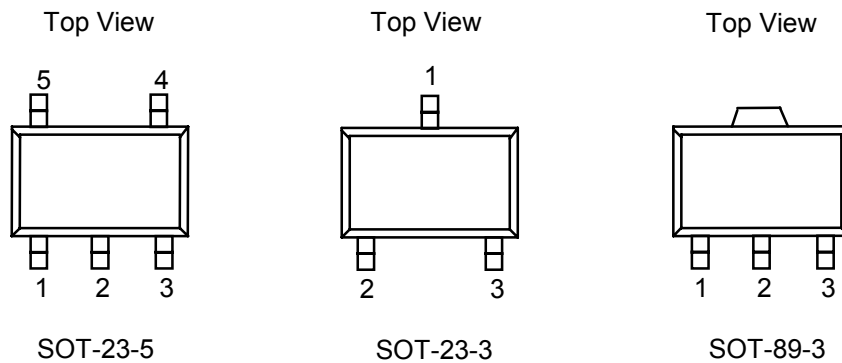


Figure 2. Pin Assignment

A type (with shutdown function)

PKG: SOT-23-5

Pin No.	Pin Name	Functions
1	ON/OFF	Shutdown pin “H”: Normal operation (step-up operating) “L”: Step-up stopped (entire circuit stopped)
2	VOUT	Output voltage pin and IC power supply pin
3	—	(N.C.)
4	VSS	GND pin
5	CONT ^{*1}	External inductor connection pin (S-8351 Series)
	EXT ^{*2}	External transistor connection pin (S-8352 Series)

B, C type (without shutdown function)

PKG: SOT-23-3

Pin No.	Pin Name	Functions
1	VOUT	Output voltage pin and IC power supply pin
2	VSS	GND pin
3	CONT ^{*1}	External inductor connection pin (S-8351 Series)
	EXT ^{*2}	External transistor connection pin (S-8352 Series)

C type (without shutdown function)

PKG: SOT-89-3

Pin No.	Pin Name	Functions
1	VSS	GND pin
2	VOUT	Output voltage pin and IC power supply pin
3	CONT ^{*1}	External inductor connection pin (S-8351 Series)
	EXT ^{*2}	External transistor connection pin (S-8352 Series)

D type (V_{DD}/V_{OUT} separate type)

PKG: SOT-23-5

Pin No.	Pin Name	Functions
1	VOUT	Output voltage pin
2	VDD	IC power supply pin
3	—	(N.C.)
4	VSS	GND pin
5	CONT ^{*1}	External inductor connection pin (S-8351 Series)
	EXT ^{*2}	External transistor connection pin (S-8352 Series)

*1. Open-drain output

*2. CMOS output

■ Absolute Maximum Ratings

Table 1. Absolute Maximum Ratings

(Unless otherwise specified, $T_a = 25^\circ\text{C}$)

Parameter	Symbol		Ratings	Unit
V _{OUT} pin voltage	V _{OUT}		V _{SS} – 0.3 to V _{SS} + 12	V
ON/ $\overline{\text{OFF}}$ pin voltage (A type)	V _{ON/$\overline{\text{OFF}}$}		V _{SS} – 0.3 to V _{SS} + 12	
V _{DD} pin voltage (D type)	V _{DD}		V _{SS} – 0.3 to V _{SS} + 12	
CONT pin voltage	V _{CONT}		V _{SS} – 0.3 to V _{SS} + 12	
EXT pin voltage	V _{EXT}	D type	V _{SS} – 0.3 to V _{DD} + 0.3	
		Other than above	V _{SS} – 0.3 to V _{OUT} + 0.3	
CONT pin current	I _{CONT}		300	mA
EXT pin current	I _{EXT}		±50	
Power dissipation	P _D	SOT-89-3	500	mW
		SOT-23-5	250	
		SOT-23-3	150	
Operating temperature	T _{opr}		–40 to +85	°C
Storage temperature	T _{sta}		–40 to +125	

Caution Although the IC contains a static electricity protection circuit, static electricity or voltage that exceeds the limit of the protection circuit should not be applied.

Electrical Characteristics

1-1. S-8351 Series

Table 2. Electrical Characteristics

(Unless otherwise specified, Ta = 25°C)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit	Test Circuit
Output voltage	V_{OUT}	—	$V_{OUT(S)} \times 0.976$	$V_{OUT(S)}$	$V_{OUT(S)} \times 1.024$	V	1
Input voltage	V_{IN}	—	—	—	10	V	1
Operation start voltage	V_{ST1}	$I_{OUT} = 1 \text{ mA}$	—	—	0.9	V	1
Oscillation start voltage	V_{ST2}	No external parts, voltage applied to VOUT CONT pulled up to VOUT via 300 Ω resistor	—	—	0.8	V	2
Input current without load	I_{IN}	$I_{OUT} = 0 \text{ mA}$	S-8351x15 to 29	—	8.5	μA	1
			S-8351x30 to 49	—	9.0		
			S-8351x50 to 65	—	9.5		
Current consumption 1	I_{SS1}	$V_{OUT} = \text{Output voltage} \times 0.95$	S-8351x15 to 19	—	9.6	μA	2
			S-8351x20 to 29	—	15.7		
			S-8351x30 to 39	—	23.2		
			S-8351x40 to 49	—	32.0		
			S-8351x50 to 59	—	42.1		
			S-8351x60 to 65	—	54.9		
Current consumption 2	I_{SS2}	$V_{OUT} = \text{Output voltage} + 0.5$	S-8351x15 to 19	—	2.3	μA	2
			S-8351x20 to 29	—	2.5		
			S-8351x30 to 39	—	2.7		
			S-8351x40 to 49	—	2.9		
			S-8351x50 to 59	—	3.1		
			S-8351x60 to 65	—	3.3		
Current consumption during shutdown (A type)	I_{SSS}	Shutdown pin = 0 V	—	—	0.5	μA	2
Switching current	I_{SW}	$V_{CONT} = 0.4 \text{ V}$	S-8351x15 to 19	50.2	91.2	mA	2
			S-8351x20 to 24	65.0	118.2		
			S-8351x25 to 29	78.5	142.7		
			S-8351x30 to 39	90.7	164.8		
			S-8351x40 to 49	110.9	201.6		
			S-8351x50 to 59	125.7	228.6		
Switching transistor leakage current	I_{SWQ}	No external parts, $V_{CONT} = V_{OUT} = 10 \text{ V}$ Shutdown pin = 0 V	—	—	0.5	μA	2
CONT limit voltage	$V_{CONTLMT}$	Apply to CONT pin, confirm oscillation stop	—	0.9	—	V	2
Line regulation	ΔV_{OUT1}	$V_{IN} = V_{OUT(S)} \times 0.4 \text{ to } \times 0.6$	—	30	60	mV	1
Load regulation	ΔV_{OUT2}	$I_{OUT} = 10 \mu\text{A to } V_{OUT(S)}/250 \times 1.25$	—	30	60	mV	1
Output voltage temperature coefficient	$\frac{\Delta V_{OUT}}{\Delta T_a \cdot V_{OUT}}$	Ta = -40°C to +85°C	—	±50	—	ppm/°C	1
Maximum oscillation frequency	f_{OSC}	$V_{OUT} = \text{Output voltage} \times 0.95$, measure waveform at CONT pin	90	100	110	kHz	2
Duty ratio 1	Duty1	$V_{OUT} = \text{Output voltage} \times 0.95$, measure waveform at CONT pin	70	75	80	%	2
Duty ratio 2 (A, B, D type)	Duty2	Measure waveform at CONT pin with light load	—	50	—	%	1
Shutdown pin input voltage (A type)	V_{SH}	$V_{OUT} = \text{Output voltage} \times 0.95$, judge oscillation at CONT pin	0.75	—	—	V	2
	V_{SL1}	$V_{OUT} = \text{Output voltage} \times 0.95$, judge stop at CONT pin	—	—	0.3		
	V_{SL2}	When $V_{OUT} \geq 1.5 \text{ V}$ When $V_{OUT} < 1.5 \text{ V}$	—	—	0.2		
Shutdown pin input current (A type)	I_{SH}	Shutdown pin = 10 V	-0.1	—	0.1	μA	2
	I_{SL}	Shutdown pin = 0 V	-0.1	—	0.1		
Efficiency	EFFI	—	S-8351x30	—	86	%	1
		—	S-8351x50	—	88		

External parts

Coil: CDRH6D28-101 (100 μH) from Sumida Corporation
 Diode: MA2Z748 (Schottky type) from Matsushita Electronic Components Co., Ltd.
 Capacitor: F93 (16 V, 47 μF tantalum type) from Nichicon Corporation)

$V_{IN} = V_{OUT(S)} \times 0.6$ applied, $I_{OUT} = V_{OUT(S)} / 250 \Omega$

Shutdown function built-in type (A type): ON/OFF pin is connected to V_{OUT}

V_{DD}/V_{OUT} separate type (D type): V_{DD} pin is connected to V_{OUT} pin

Remarks 1. $V_{OUT(S)}$ specified above is the set output voltage value, and V_{OUT} is the typical value of the actual output voltage.

2. V_{DD}/V_{OUT} separate type (D type)

A step-up operation is performed from $V_{DD} = 0.8 \text{ V}$. However, $1.8 \text{ V} \leq V_{DD} \leq 10 \text{ V}$ is recommended to stabilize the output voltage and oscillation frequency. ($V_{DD} \geq 1.8 \text{ V}$ must be applied for products with a set value of less than 1.9 V.)

2-1. S-8352 Series

Table 3. Electrical Characteristics

(Unless otherwise specified, Ta = 25°C)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit	Test Circuit
Output voltage	V _{OUT}	—	V _{OUT(S)} × 0.976	V _{OUT(S)}	V _{OUT(S)} × 1.024	V	3
Input voltage	V _{IN}	—	—	—	10	V	3
Operation start voltage	V _{ST1}	I _{OUT} = 1 mA	—	—	0.9	V	3
Oscillation start voltage	V _{ST2}	No external parts, voltage applied to V _{OUT}	—	—	0.8	V	4
Current consumption 1	I _{SS1}	V _{OUT} = Output voltage × 0.95	S-8352x15 to 19	—	7.4	μA	4
			S-8352x20 to 29	—	12.0		
			S-8352x30 to 39	—	17.8		
			S-8352x40 to 49	—	24.7		
			S-8352x50 to 59	—	32.7		
			S-8352x60 to 65	—	43.0		
Current consumption 2	I _{SS2}	V _{OUT} = Output voltage + 0.5	S-8352x15 to 19	—	2.3	μA	4
			S-8352x20 to 29	—	2.5		
			S-8352x30 to 39	—	2.7		
			S-8352x40 to 49	—	2.9		
			S-8352x50 to 59	—	3.1		
			S-8352x60 to 65	—	3.3		
Current consumption during shutdown (A type)	I _{SSS}	Shutdown pin = 0 V	—	—	0.5	μA	4
EXT pin output current	I _{EXTH}	V _{EXT} = V _{OUT} – 0.4 V	S-8352x15 to 19	–3.5	–6.3	mA	4
			S-8352x20 to 24	–5.2	–9.4		
			S-8352x25 to 29	–6.8	–12.3		
			S-8352x30 to 39	–8.2	–14.9		
			S-8352x40 to 49	–10.7	–19.4		
			S-8352x50 to 59	–12.5	–22.8		
	I _{EXTL}	V _{EXT} = 0.4 V	S-8352x15 to 19	3.8	6.9	mA	4
			S-8352x20 to 24	5.6	10.2		
			S-8352x25 to 29	7.3	13.3		
			S-8352x30 to 39	8.9	16.2		
			S-8352x40 to 49	11.6	21.1		
			S-8352x50 to 59	13.7	25.0		
Line regulation	ΔV _{OUT1}	V _{IN} = V _{OUT(S)} × 0.4 to × 0.6	—	30	60	mV	3
Load regulation	ΔV _{OUT2}	I _{OUT} = 10 μA to V _{OUT(S)} /100 × 1.25	—	30	60	mV	3
Output voltage temperature coefficient	$\frac{\Delta V_{OUT}}{\Delta T_a \cdot V_{OUT}}$	Ta = –40°C to +85°C	—	±50	—	ppm/°C	3
Maximum oscillation frequency	f _{OSC}	V _{OUT} = Output voltage × 0.95, measure waveform at EXT pin	90	100	110	kHz	4
Duty ratio 1	Duty1	V _{OUT} = Output voltage × 0.95, measure waveform at EXT pin	70	75	80	%	4
Duty ratio 2 (A, B, D type)	Duty2	Measure waveform at EXT pin with light load	—	50	—	%	3
Shutdown pin input voltage (A type)	V _{SH}	V _{OUT} = Output voltage × 0.95, measure oscillation at EXT pin	0.75	—	—	V	4
	V _{SL1}	V _{OUT} = Output voltage × 0.95, judge stop at EXT pin	—	—	0.3		
	V _{SL2}	When V _{OUT} ≥ 1.5 V	—	—	0.2		
Power off pin input current (A type)	I _{SH}	Shutdown pin = 10 V	–0.1	—	0.1	μA	4
	I _{SL}	Shutdown pin = 0 V	–0.1	—	0.1		
Efficiency	EFFI	—	S-8352x30	—	83	%	3
		—	S-8352x50	—	85		

External parts

Coil: CDRH6D28-101 (100 μH) from Sumida Corporation
Diode: MA2Z748 (Schottky type) from Matsushita Electronic Components Co., Ltd.
Capacitor: F93 (16 V, 47 μF tantalum type) from Nichicon Corporation
Transistor: CPH3210 from Sanyo Electric Co., Ltd.
Base resistor (Rb): 1 kΩ
Base capacitor (Cb): 2200 pF (ceramic type)

V_{IN} = V_{OUT(S)} × 0.6 applied, I_{OUT} = V_{OUT(S)} / 100 Ω

Shutdown function built-in type (A type): ON/OFF pin is connected to V_{OUT}

V_{DD}/V_{OUT} separate type (D type): VDD pin is connected to V_{OUT} pin

Remarks 1. V_{OUT(S)} specified above is the set output voltage value, and V_{OUT} is the typical value of the actual output voltage.

2. V_{DD}/V_{OUT} separate type (D type)

A step-up operation is performed from V_{DD} = 0.8 V. However, 1.8 V ≤ V_{DD} ≤ 10 V is recommended to stabilize the output voltage and oscillation frequency. (V_{DD} ≥ 1.8 V must be applied for products with a set value of less than 1.9 V.)

Test Circuits

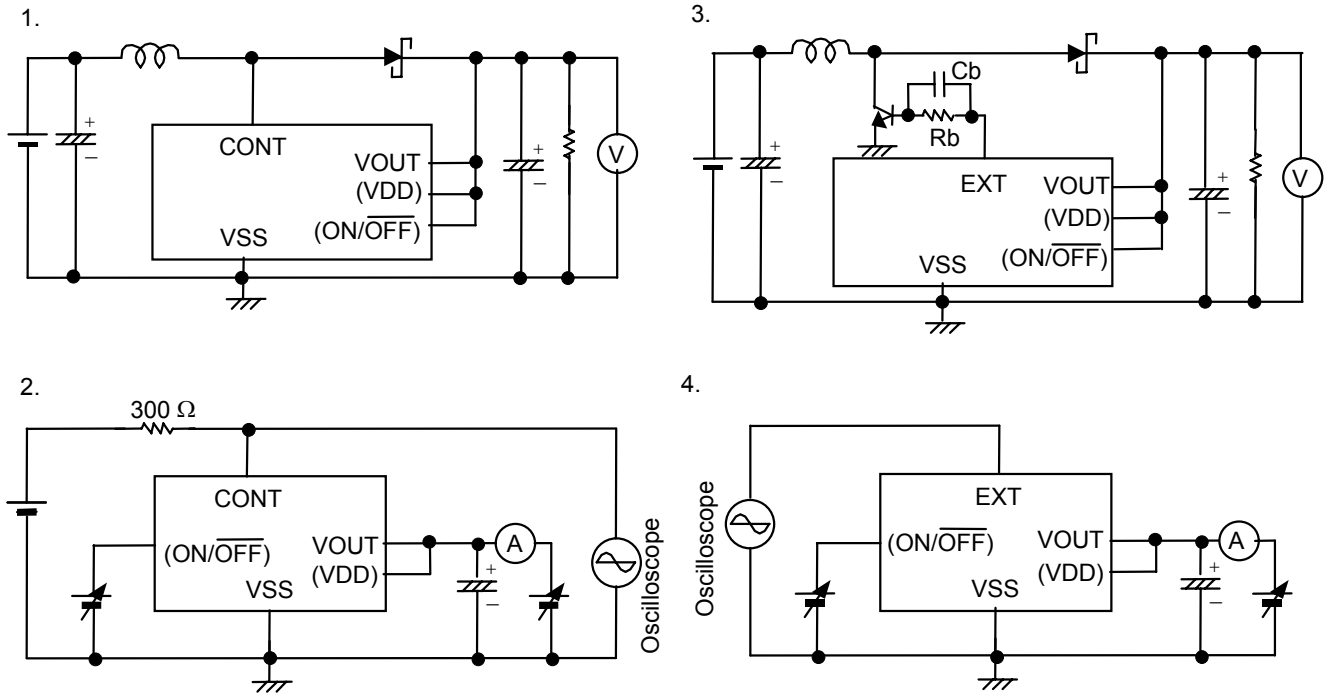


Figure 3. Test Circuits 1, 2, 3, and 4

■ Operation

1. Step-up DC/DC Converter

The S-8351/52 Series is a DC/DC converter that uses a pulse frequency modulation method (PFM) and features low current consumption. This series is an especially efficient DC/DC converter at an output current of 100 μ A or lower.

In conventional fixed-duty PFM DC/DC converters, although a low duty ratio allows a lower ripple voltage when the current load is light, the efficiency is decreased when the output load current is large. Conversely, a high duty ratio increases the output load current and efficiency, but increases the ripple voltage when the output load current is low.

In the A, B, and D types, the duty ratio is automatically switched 75% when the output load current is high to secure the load drive capability, and 50% when the output load current is low to control the load drive capability to decrease pulse skipping. This suppresses a drop in the ripple frequency, enabling control of the increase in the ripple voltage. The C type adopts a 75% fixed-duty PFM method. The ripple voltage increases more than that of the duty switching type with the load is low, but the efficiency is better.

In the A, B, and D types, the duty ratio is not rapidly changed, but rather smoothly switched in the intermediate area between 50% and 75%. Therefore, fluctuation of the ripple voltage caused by duty switching is minimized. Figures 4 and 5 show the ripple voltage characteristics versus the output current. These figures show that the ripple voltage decreases as the output load current (I_{OUT}) changes from large to small. The ripple voltage becomes particularly small when I_{OUT} is in the coil current discontinuous region of 20 mA or less.

S-8351A30MC

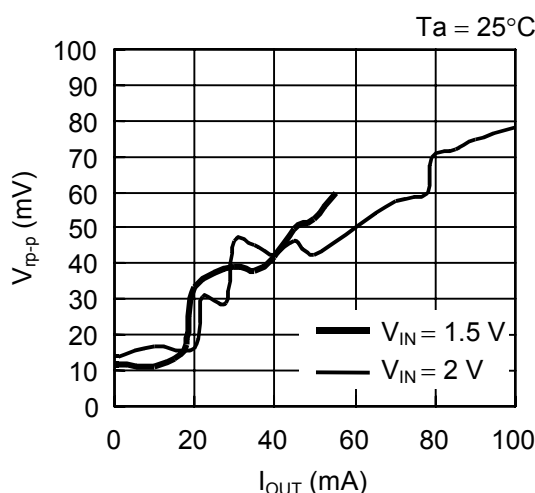


Figure 4. Ripple Voltage Characteristics vs. Output Current (S-8351A30MC)

S-8351A50MC

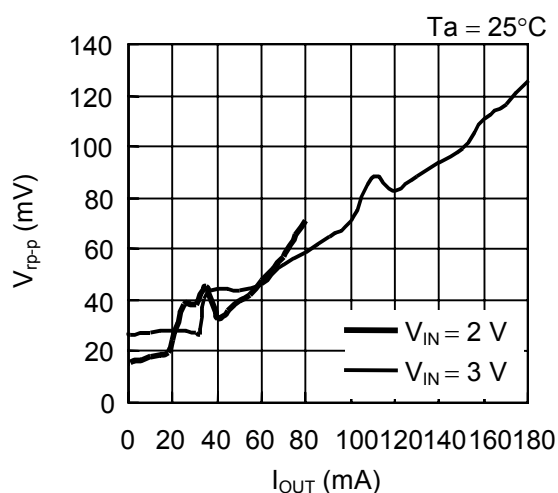


Figure 5. Ripple Voltage Characteristics vs. Output Current (S-8351A50MC)

Shutdown pin: Stops or starts step-up operation.
(Only for product type A)

Setting the shutdown pin to the “L” level stops operation of all the internal circuits and reduces the current consumption significantly.

DO NOT use the shutdown pin in a floating state because it has the structure shown in Figure 6 and is not pulled up or pulled down internally. DO NOT apply a voltage of between 0.3 V and 0.75 V to the shutdown pin because applying such a voltage increases the current consumption. If the shutdown pin is not used, connect it to the VOUT pin.

The shutdown pin does not have hysteresis.

Shutdown Pin	CR Oscillator	Output Voltage
"H"	Operating	Fixed
"L"	Stopped	$\cong V_{IN}^*$

* Voltage obtained by subtracting the voltage drop due to the DC resistance of the inductor and the diode forward voltage from V_{IN} .

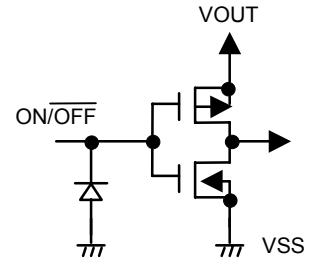


Figure 6. Shutdown Pin Structure

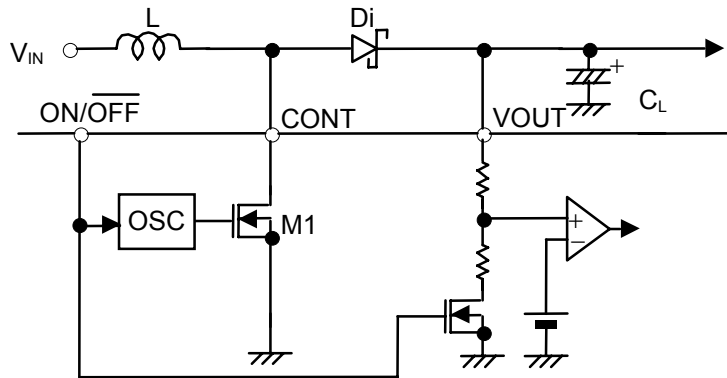


Figure 7. Step-Up Switching Regulator Circuit for Basic Equation

The following are the basic equations [(1) through (7)] of the step-up switching regulator (see **Figure 7**).
Voltage at CONT pin at the moment M1 is turned ON (current (I_L) flowing through L is zero), V_A :

$$V_A = V_S \quad \dots\dots\dots (1)$$

(V_S : Non-saturated voltage of M1)

The change in I_L over time:

$$\frac{dI_L}{dt} = \frac{V_L}{L} = \frac{V_{IN} - V_S}{L} \quad \dots\dots\dots (2)$$

Integration of the above equation (I_L):

$$I_L = \left(\frac{V_{IN} - V_S}{L} \right) \cdot t \quad \dots\dots\dots (3)$$

I_L flows while M1 is ON (t_{ON}). The time of t_{ON} is determined by the oscillation frequency of OSC.
The peak current (I_{PK}) after t_{ON} :

$$I_{PK} = \left(\frac{V_{IN} - V_S}{L} \right) \cdot t_{ON} \quad \dots\dots\dots (4)$$

The energy stored in L is represented by $1/2 \cdot L (I_{PK})^2$.
When M1 is turned OFF (t_{OFF}), the energy stored in L is emitted through a diode.
Then, the reverse voltage (V_L) is generated:

$$V_L = (V_{OUT} + V_D) - V_{IN} \quad \dots\dots\dots (5)$$

(V_D : Diode forward voltage)

The voltage at CONT pin rises only by $V_{OUT} + V_D$.

The change in the current (I_L) flowing through the diode into V_{OUT} during t_{OFF} :

$$\frac{dI_L}{dt} = \frac{V_L}{L} = \frac{V_{OUT} + V_D - V_{IN}}{L} \quad \dots\dots\dots (6)$$

Integration of the above equation is as follows:

$$I_L = I_{PK} - \left(\frac{V_{OUT} + V_D - V_{IN}}{L} \right) \cdot t \quad \dots\dots\dots (7)$$

During t_{ON} , the energy is stored in L and is not transmitted to V_{OUT} . When receiving the output current (I_{OUT}) from V_{OUT} , the energy of the capacitor (C_L) is consumed. As a result, the pin voltage of C_L is reduced, and goes to the lowest level after M1 is turned ON (t_{ON}). When M1 is turned OFF, the energy stored in L is transmitted through the diode to C_L , and the voltage of C_L rises rapidly. V_{OUT} is a time function, and therefore indicates the maximum value (ripple voltage: V_{P-P}) when the current flowing through into V_{OUT} and load current (I_{OUT}) match.

Next, the ripple voltage is determined as follows:

I_{OUT} vs. t_1 (time) from when M1 is turned OFF (after t_{ON}) to when V_{OUT} reaches the maximum level:

$$I_{OUT} = I_{PK} - \left(\frac{V_{OUT} + V_D - V_{IN}}{L} \right) \cdot t_1 \quad \dots\dots\dots (8)$$

$$\therefore t_1 = (I_{PK} - I_{OUT}) \cdot \left(\frac{L}{V_{OUT} + V_D - V_{IN}} \right) \quad \dots\dots\dots (9)$$

When M1 is turned OFF (t_{OFF}), $I_L = 0$ (when the energy of the inductor is completely transmitted):

Based on equation (7),

$$\left(\frac{L}{V_{OUT} + V_D - V_{IN}} \right) = \frac{t_{OFF}}{I_{PK}} \quad \dots\dots\dots (10)$$

When substituting equation (10) for equation (9),

$$t_1 = t_{OFF} - \left(\frac{I_{OUT}}{I_{PK}} \right) \cdot t_{OFF} \quad \dots\dots\dots (11)$$

Electric charge ΔQ_1 which is charged in C_L during t_1 :

$$\begin{aligned} \Delta Q_1 &= \int_0^{t_1} I_L dt = I_{PK} \cdot \int_0^{t_1} dt - \frac{V_{OUT} + V_D - V_{IN}}{L} \cdot \int_0^{t_1} t dt \\ &= I_{PK} \cdot t_1 - \frac{V_{OUT} + V_D - V_{IN}}{L} \cdot \frac{1}{2} t_1^2 \quad \dots\dots\dots (12) \end{aligned}$$

When substituting equation (12) for equation (9):

$$\Delta Q_1 = I_{PK} - \frac{1}{2} (I_{PK} - I_{OUT}) \cdot t_1 = \frac{I_{PK} + I_{OUT}}{2} \cdot t_1 \quad \dots\dots\dots (13)$$

A rise in voltage (V_{P-P}) due to ΔQ_1 :

$$V_{P-P} = \frac{\Delta Q_1}{C_L} = \frac{1}{C_L} \cdot \left(\frac{I_{PK} + I_{OUT}}{2} \right) \cdot t_1 \quad \dots\dots\dots (14)$$

When taking into consideration I_{OUT} to be consumed during t_1 and the ESR (Equivalent Series Resistance) of C_L , namely R_{ESR} :

$$V_{P-P} = \frac{\Delta Q_1}{C_L} = \frac{1}{C_L} \cdot \left(\frac{I_{PK} + I_{OUT}}{2} \right) \cdot t_1 + \left(\frac{I_{PK} + I_{OUT}}{2} \right) \cdot R_{ESR} - \frac{I_{OUT} \cdot t_1}{C_L} \dots\dots\dots (15)$$

When substituting equation (11) for equation (15):

$$V_{P-P} = \frac{(I_{PK} - I_{OUT})^2}{2I_{PK}} \cdot \frac{t_{OFF}}{C_L} + \left(\frac{I_{PK} + I_{OUT}}{2} \right) \cdot R_{ESR} \dots\dots\dots (16)$$

Therefore to reduce the ripple voltage, it is important that the capacitor connected to the output pin has a large capacity and a small ESR.

■ External Part Selection

1. Inductor

To minimize the loss due to inductor DC resistance, select an inductor with the smallest possible DC resistance (less than 1 Ω). Set the inductance value to around 22 μH to 1 mH.

To make the average value of the output voltage (V_{OUT}) constant, it is necessary to supply the energy corresponding to the output current (I_{OUT}) from the inductor. The amount of charge required for I_{OUT} is $I_{OUT} \times (t_{ON} + t_{OFF})$. Because the inductor can supply energy only during t_{OFF} , the charge is obtained by integrating equation (7) with $0 \rightarrow t_{OFF}$, namely,

$$\frac{I_{PK}}{2} \cdot t_{OFF} \text{ Thus,}$$

$$\frac{I_{PK}}{2} \cdot t_{OFF} = I_{OUT} \times (t_{ON} + t_{OFF}) \dots\dots\dots (17)$$

$$I_{PK} = 2 \cdot \frac{t_{ON} + t_{OFF}}{t_{OFF}} \cdot I_{OUT} \dots\dots\dots (18)$$

When the oscillation duty ratio of OSC is 75%, $I_{PK} = 8 \cdot I_{OUT}$. Therefore, an I_{PK} current which is eight times I_{OUT} flows into transistor M1.

The S-8351 Series includes a switching current controller which monitors the current flowing into the CONT pin by the voltage (CONT control voltage) and controls the current. This controller prevents destruction of the IC due to excess current.

If an inductor with a large L value is selected, both I_{PK} and I_{OUT} decrease. Since the energy stored in the inductor is equal to $\frac{1}{2} L \cdot (I_{PK})^2$, the energy decreases because I_{PK} decreases in steps of squares offsetting the increase of L. As a result, stepping up at a low voltage becomes difficult and the minimum operating input voltage becomes high. However, the DC resistance loss of L and the M1 transistor decreases by the amount I_{PK} decreased, and the inductance efficiency improves.

On the other hand, if an inductor with a smaller L value is selected, both I_{PK} and I_{OUT} increase. Accordingly, the minimum operating input voltage becomes low but the inductance efficiency deteriorates.

Caution An excessively large I_{PK} may cause magnetic saturation for some core materials, leading to the destruction of the IC. Use a core with material that satisfies $I_{sat} > I_{PK}$ (I_{sat} : Level of current that causes magnetic saturation).

2. Diode

Use an external diode that meets the following requirements:

- Low forward voltage: $V_F < 0.3V$
- High switching speed: 500 ns max.
- Reverse voltage: $V_{OUT} + V_F$ or more
- Rated current: I_{PK} or more

3. Capacitors (C_{IN} , C_L)

A capacitor at the input side (C_{IN}) improves the efficiency by reducing the power impedance and stabilizing the input current. Select the C_{IN} value according to the impedance of the power supply used. The capacitor value should be around 10 μ F.

A capacitor at the output side (C_L) is used for smoothing the ripple voltage. Therefore, select a capacitor with a small ESR (Equivalent Series Resistance) and a large capacitance. The capacitor value should be 10 μ F min. A tantalum electrolytic capacitor and an organic semiconductor capacitor are especially recommended because of their superior low-temperature and leakage current characteristics.

4. External transistor (S-8352 Series)

For the S-8352 Series, connecting an external transistor increases the output current. A bipolar (NPN) transistor or an enhancement (Nch) MOS FET transistor can be used as the external transistor.

4.1 Bipolar transistor

A circuit example using a bipolar transistor (NPN), the CPH3210 ($h_{FE} = 200$ to 560) from Sanyo, is shown in Figure 12 and 13. The h_{FE} and R_b values of the bipolar transistor determine the driving capacity to increase the output current using a bipolar transistor. A peripheral circuit example of the transistor is shown in Figure 8.

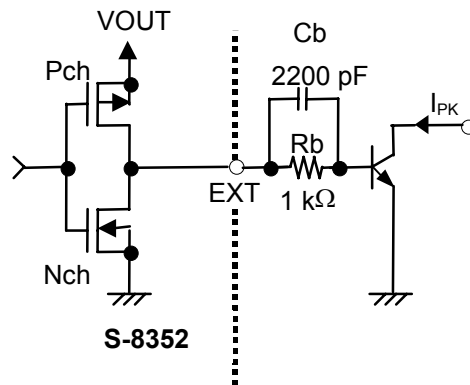


Figure 8. External Transistor Peripheral Circuit

The recommended R_b value is around 1 k Ω . Actually, determine the required base current I_b from the bipolar transistor h_{FE} assuming $I_b = I_{PK}/h_{FE}$, and select the smaller R_b value:

$$R_b = \frac{V_{OUT} - 0.7}{I_b} - \frac{0.4}{|I_{EXTH}|} \quad \left(R_b = \frac{V_{DD} - 0.7}{I_b} - \frac{0.4}{|I_{EXTH}|} \right)$$

A small R_b value can increase the output current, but reduces the efficiency. Since a current may flow on the pulse and the voltage may drop due to wiring resistance or other factors, a test should be performed to determine the optimum value.

If the speed-up capacitor (C_b) is inserted in parallel with the R_b resistor as shown in Figure 8, the switching loss is decreased and the efficiency is improved.

Select the C_b value according to:

$$C_b \leq \frac{1}{2\pi \cdot R_b \cdot f_{OSC} \cdot 0.7}$$

However, the best C_b value varies depending on the characteristics of the bipolar transistor to be used, so determine the optimum value via testing.

4.2 Enhancement MOS FET type

Figure 9 is a circuit example using a MOS FET transistor (N-channel).

An N-channel power MOS FET should be used for MOS FET. In particular, the EXT pin of the S-8352 can drive a MOS FET with a gate capacitance of around 1000 pF. Because the gate voltage and current of the external power MOS FET are supplied from the stepped-up output voltage V_{OUT} , the MOS FET is driven more effectively.

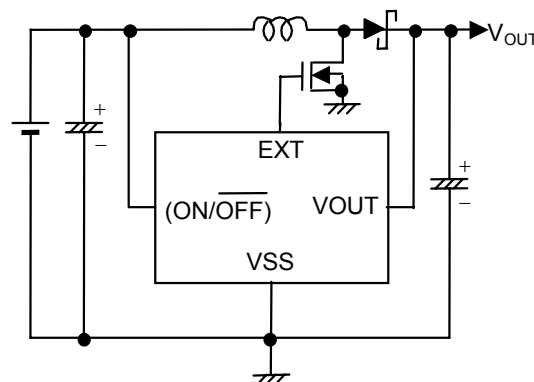


Figure 9. Circuit Example Using MOS FET

A large current may flow during startup, depending on the MOS FET selection. The S-8352 Series does not feature overcurrent protection for the external MOS FET, so perform sufficient evaluation using the devices to be actually used.

Since the on-resistance of the MOS FET might affect the output current as well as the efficiency, the threshold voltage should be low. When the output voltage is as low as 2.0 V, like in the S-8352A20, the circuit operates only when the MOS FET has a threshold voltage lower than 2.0 V.

5. V_{DD}/V_{OUT} separate type (S-8351/52 Series D type)

The S-8351/52 Series D type provides separate internal circuit power supply and output voltage setting pins (V_{DD} and V_{OUT} , respectively), making it ideal for the following applications.

- <1> Changing the output voltage value using an external resistor
- <2> Setting a high output voltage value, such as +15 V

In this case, observe the following points when using this product.

- i) A step-up operation is performed from $V_{DD} = 0.8$ V. However, $1.8 \text{ V} \leq V_{DD} \leq 10 \text{ V}$ is recommended to stabilize the output voltage and oscillation frequency. ($V_{DD} \geq 1.8 \text{ V}$ must be applied for products with a set value of less than 1.9 V.)

If V_{DD} is within the above range, the V_{DD} pin can be connected to either the input voltage pin V_{IN} or the output pin V_{OUT} .

- ii) There is impedance between the V_{OUT} pin and V_{SS} pin in the IC, so select external resistors R_a and R_b so that there are no negative effects when setting the output voltage.

The internal resistance between the V_{OUT} and V_{SS} pins are as follows.

- <1> S-835XD18 → 5.6 M Ω to 14.9 M Ω
- <2> S-835XD20 → 5.2 M Ω to 12.3 M Ω
- <3> S-835XD50 → 3.8 M Ω to 10.4 M Ω

- iii) If unstable operation such as oscillation of the output voltage occurs, add capacitor C_c in parallel with the R_a resistor. Determine the C_c value using the following equation.

$$C_c(\text{F}) = \frac{1}{2 \cdot \pi \cdot R_a \cdot 20 \text{ kHz}}$$

Standard Circuits

(1) S-8351 Series A, B, C type

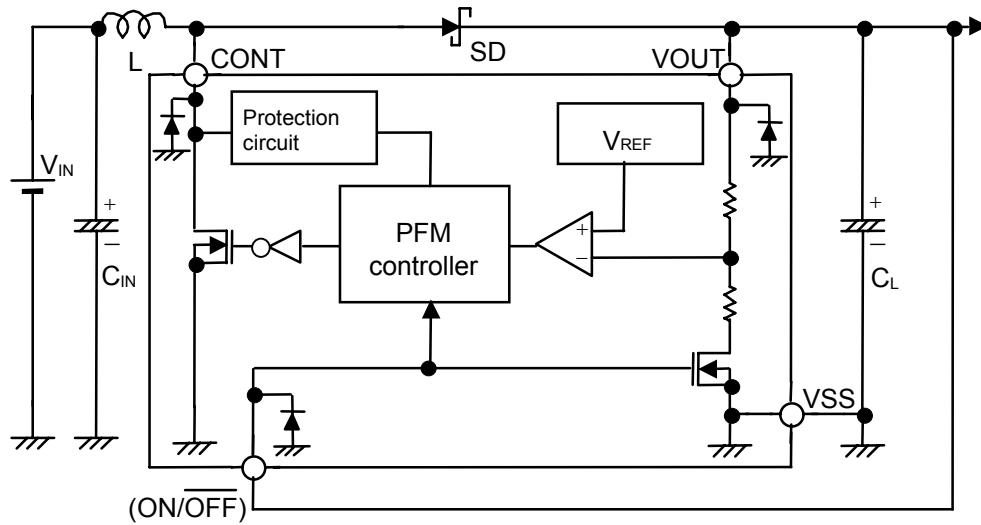


Figure 10. Standard Circuit (1)

(2) S-8351 Series D type

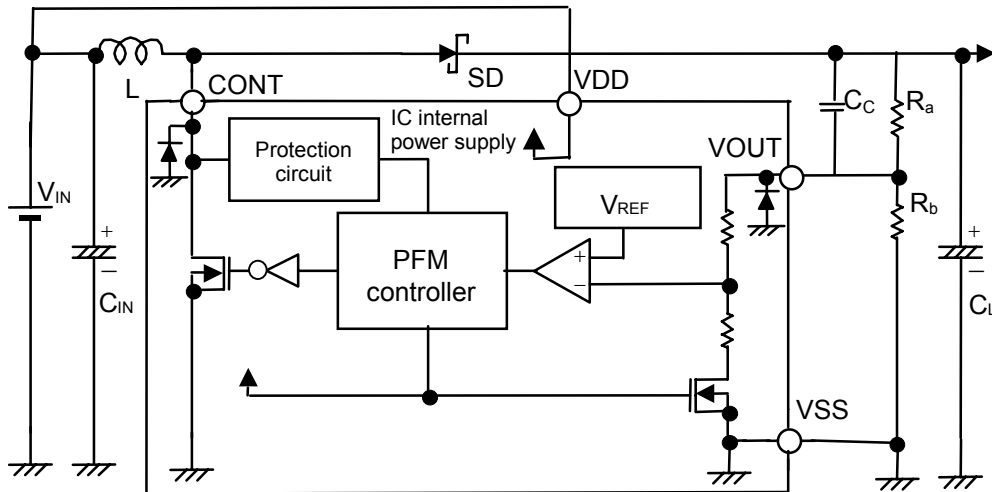


Figure 11. Standard Circuit (2)

(3) S-8352 Series A, B, C type

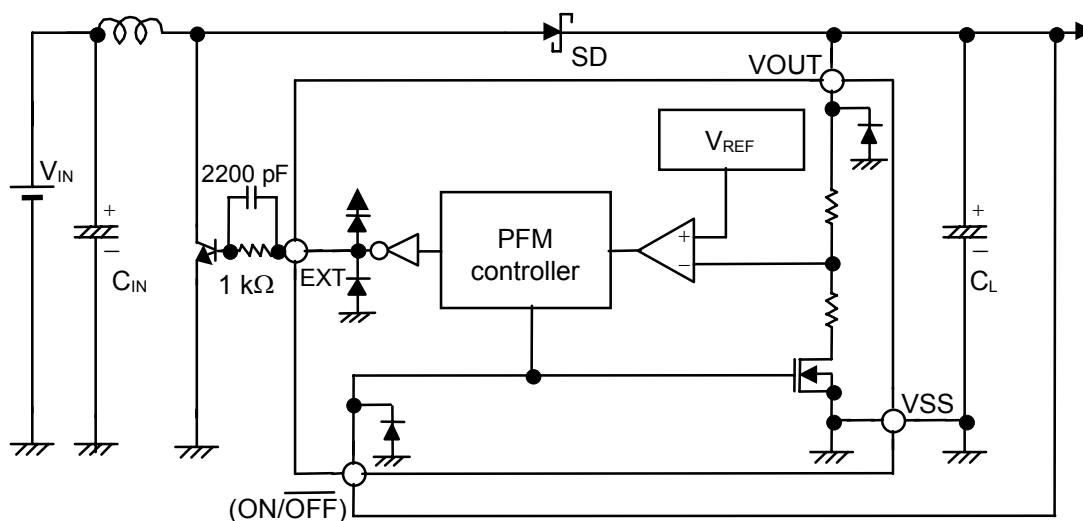


Figure 12. Standard Circuit (3)

(4) S-8352 Series D type

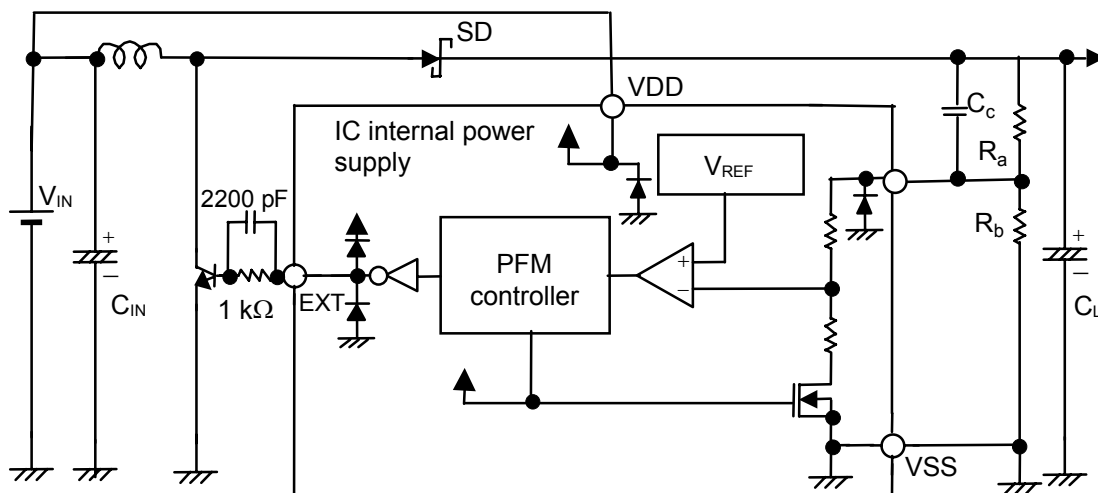


Figure 13. Standard Circuit (4)

Caution The above connection diagram and constants do not guarantee correct operation.
Perform sufficient evaluation using the actual application to set the constants.

■ Power Dissipation of Package

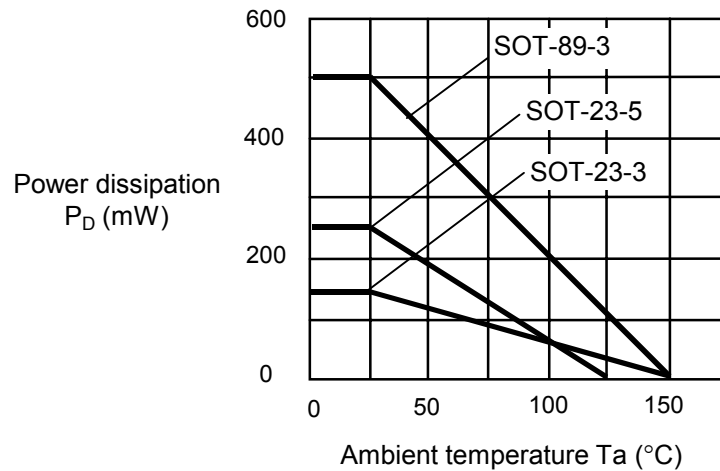


Figure 12. Power Dissipation of Package (Before Mounting)

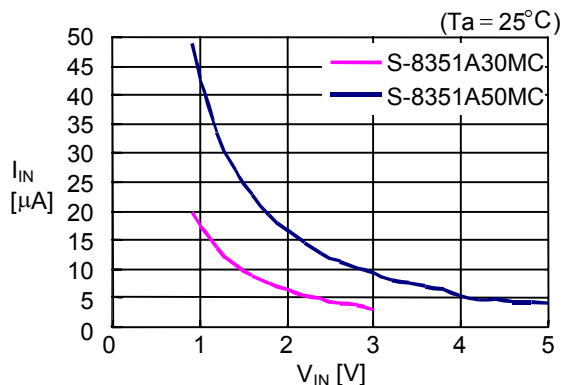
■ Cautions

- Mount the external capacitors, diode, and coil as close as possible to the IC.
- Ripple voltage and spike noise occur in switching regulators. Because they largely depend on the coil and the capacitor used, check these parameters using the actually mounted model.
- Seiko Instruments shall not be responsible for any patent infringement by products including S-8351/8352 Series in connection with the method of using S-8351/8352 Series in such products, the specification of such products, or the country of destination thereof.
- Ensure that the dissipation of the switching transistor (especially at high temperatures) does not exceed the allowable power dissipation of the package.
- When the impedance of the power supply is high, the shutdown pin is switched from “L” to “H”, or VIN is connected to the power supply, note that the power supply voltage drops temporarily because a rush current flows into the power supply.

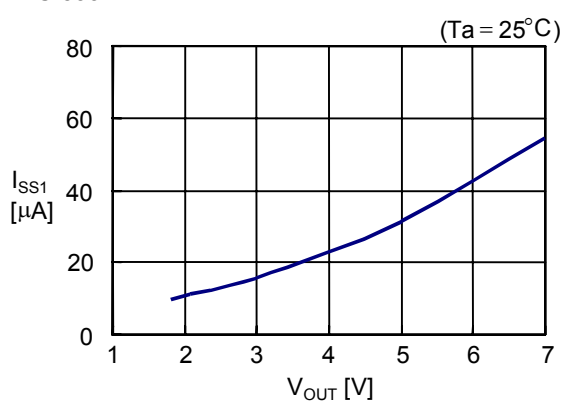
■ Characteristics (All Data Indicates Typical Values)

1. Current consumption vs. Power supply voltage

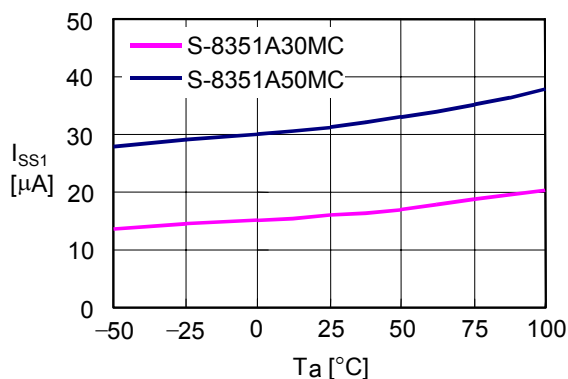
- Power supply input current no load



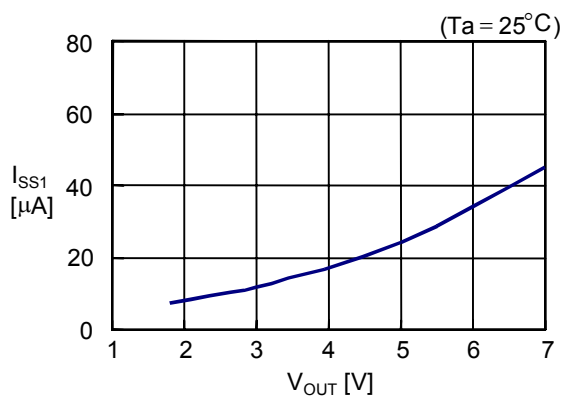
- I_{SS1} vs. V_{OUT} , T_a



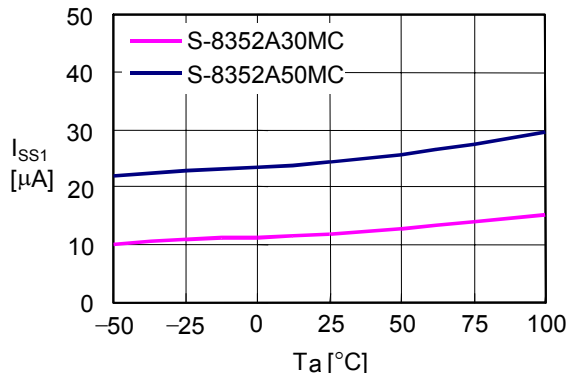
S-8351A



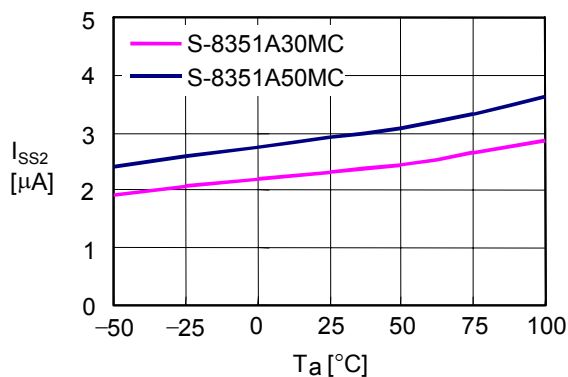
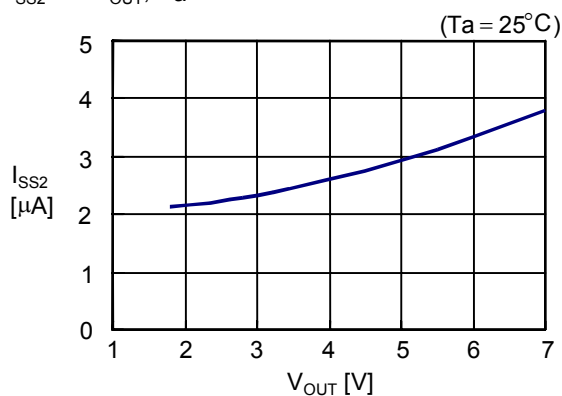
S-8352A

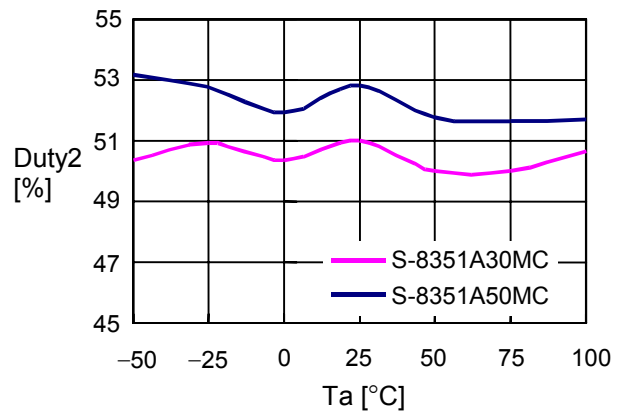
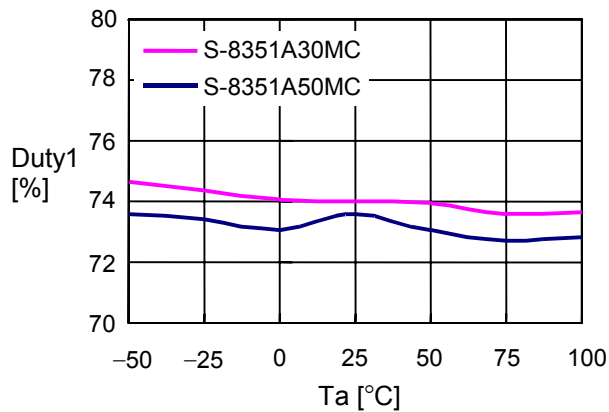
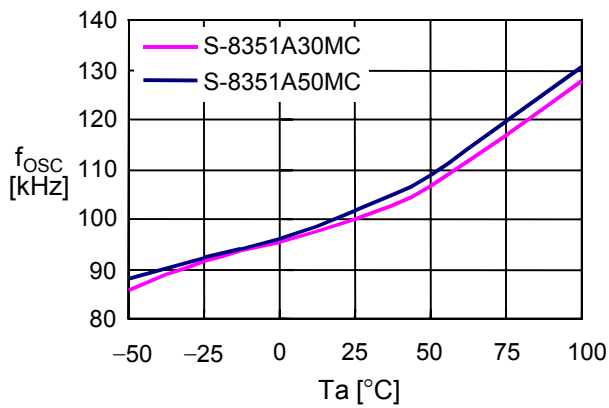
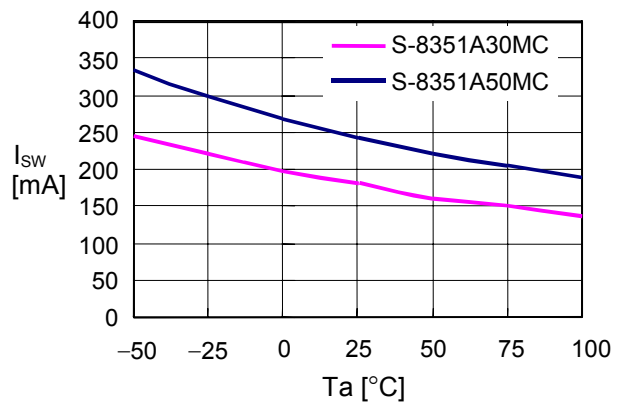
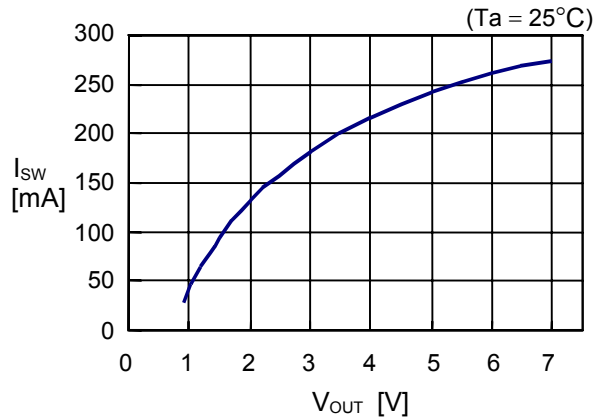
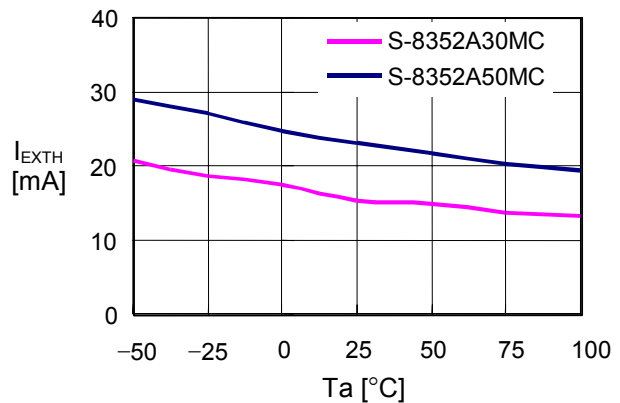
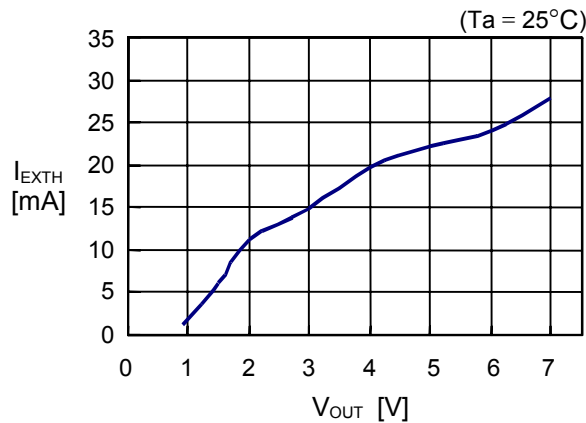


S-8352A

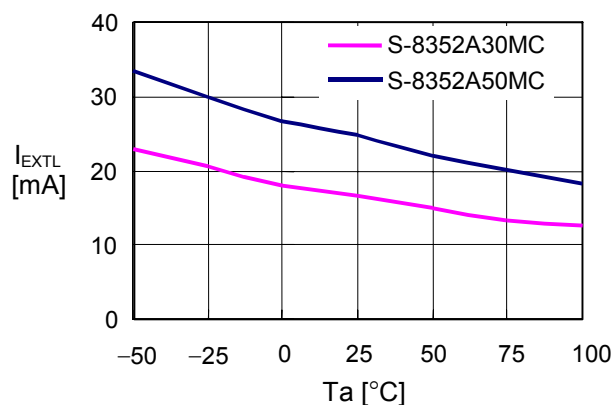
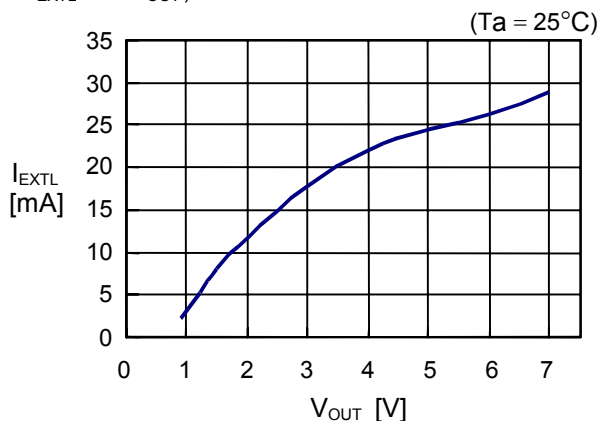


- I_{SS2} vs. V_{OUT} , T_a



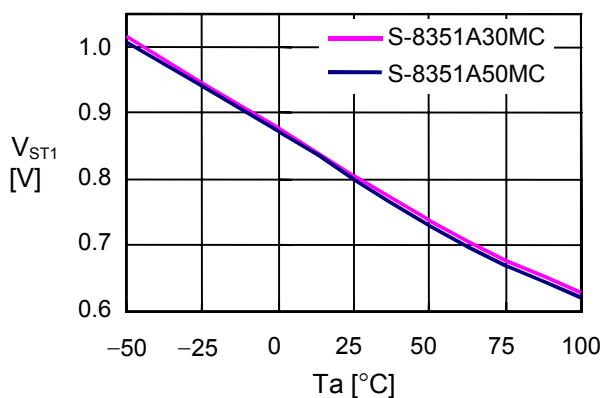
2. Oscillation frequency, duty ratio vs. Temperature**3. Switching current vs. Output voltage, temperature**• I_{SW} vs. V_{OUT} , T_a **4. EXT pin output current vs. Output voltage, temperature**• I_{EXTH} vs. V_{OUT} , T_a 

• I_{EXTL} vs. V_{OUT} , T_a

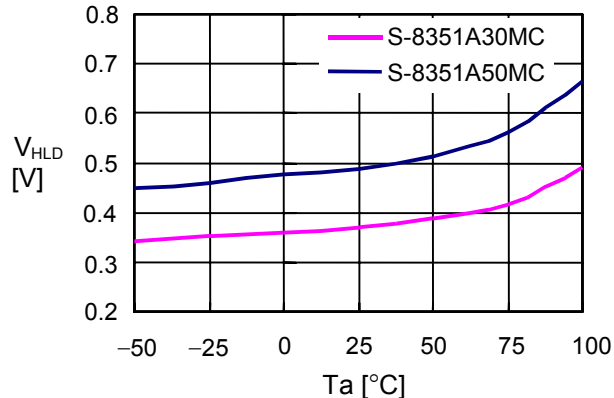


5. Operation start voltage, retention voltage vs. Temperature

• V_{ST1} vs. T_a



• V_{HLD} vs. T_a

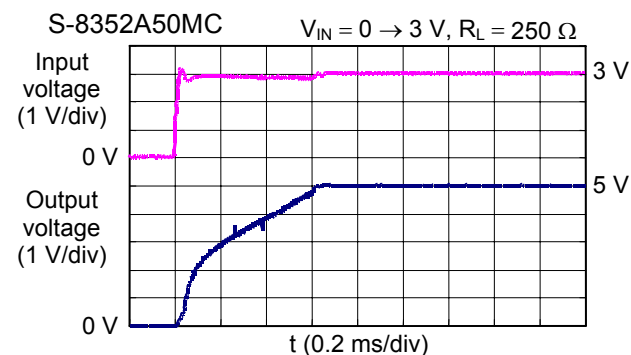
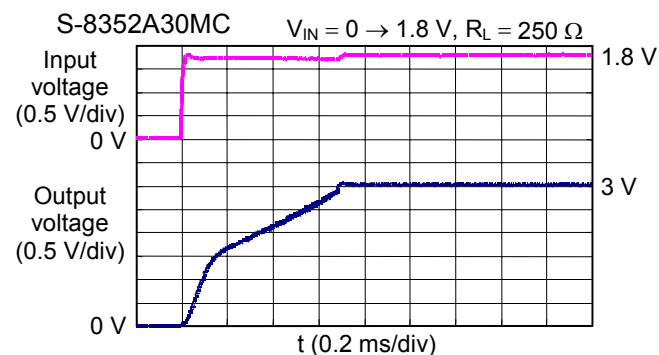
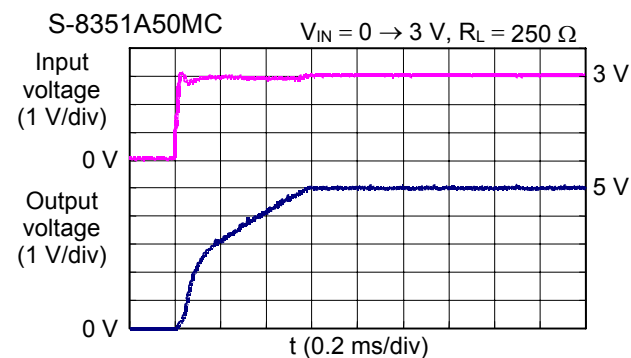
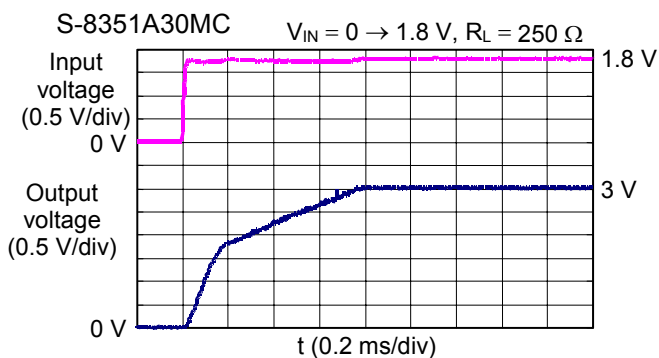


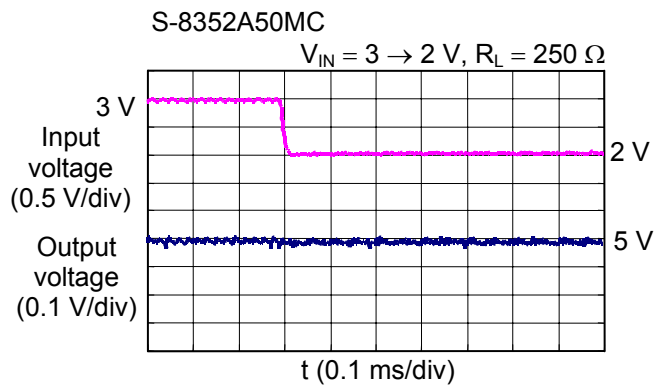
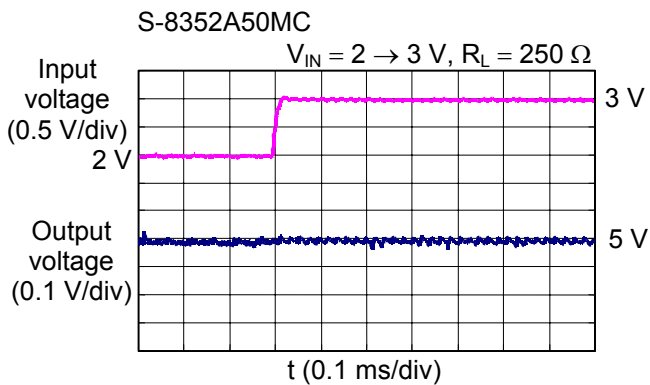
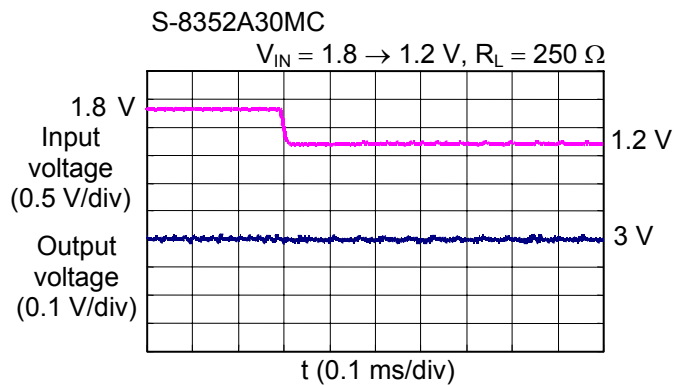
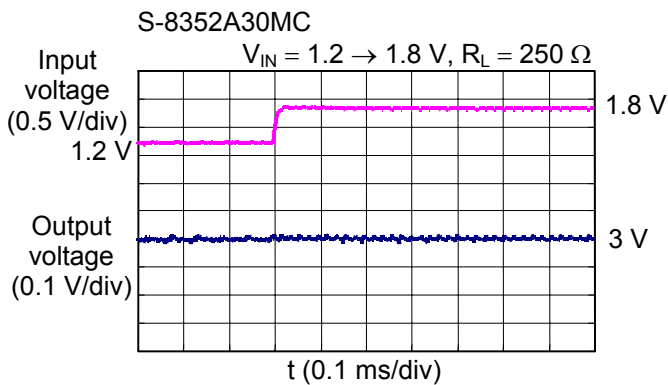
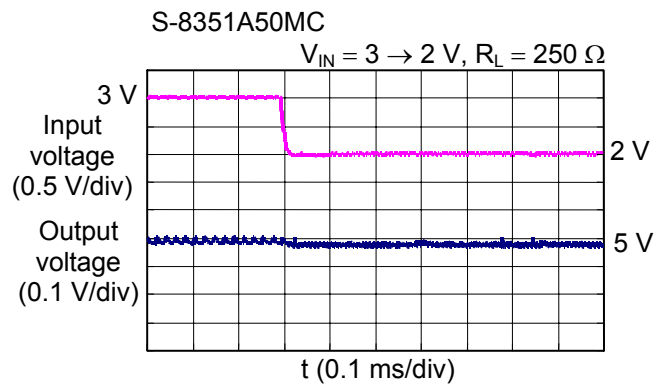
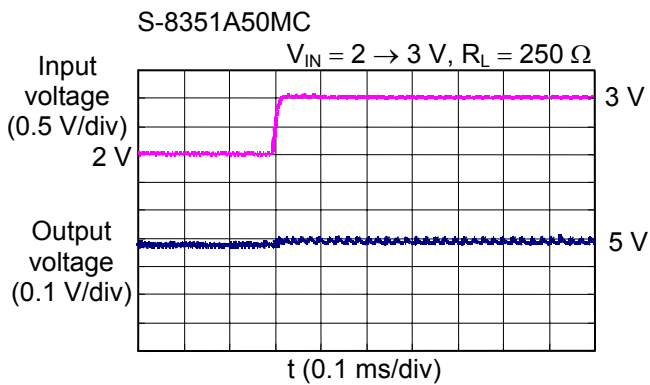
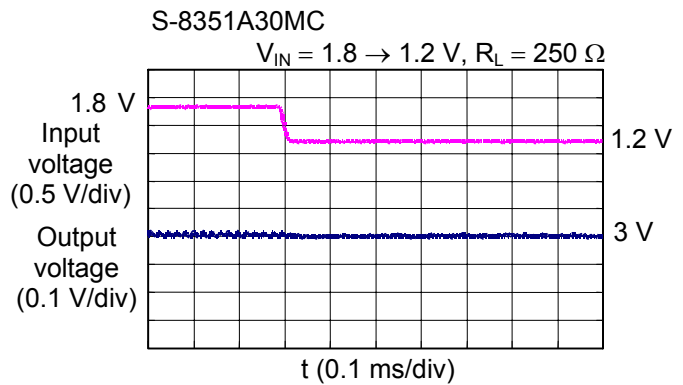
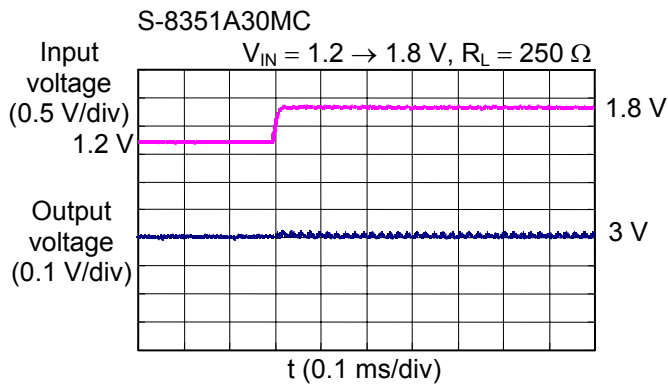
■ Reference Data (1)

1. Transient response characteristics

The conditions for external parts are the same as those specified in the electrical characteristics.

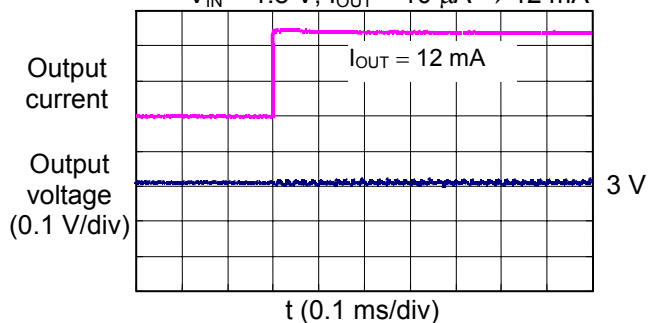
1.1 Power-on ($T_a = 25^\circ\text{C}$)



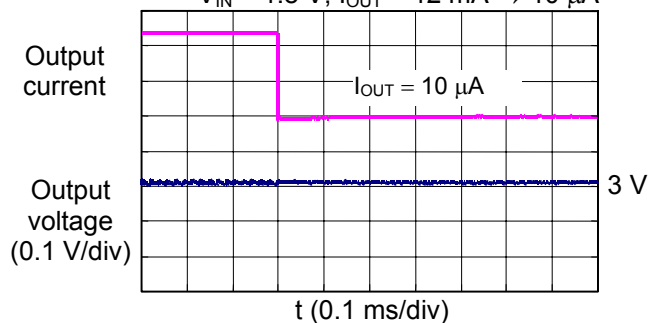
1.2 Power supply voltage fluctuation ($T_a = 25^\circ\text{C}$)

1.3 Load current fluctuation ($T_a = 25^\circ\text{C}$)

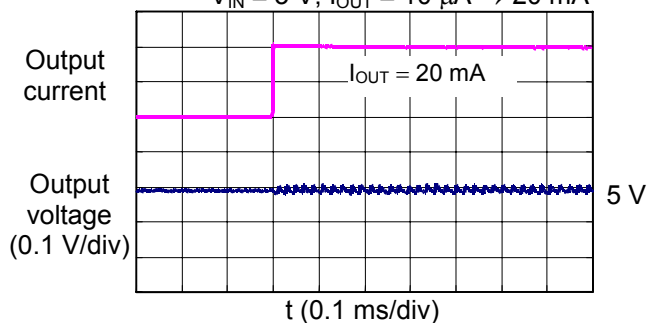
S-8351A30MC

 $V_{IN} = 1.8\text{ V}$, $I_{OUT} = 10\text{ }\mu\text{A} \rightarrow 12\text{ mA}$ 

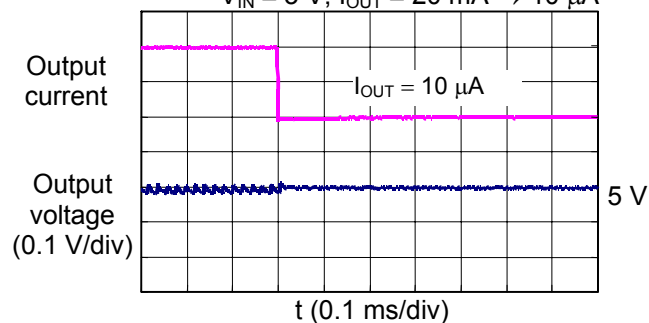
S-8351A30MC

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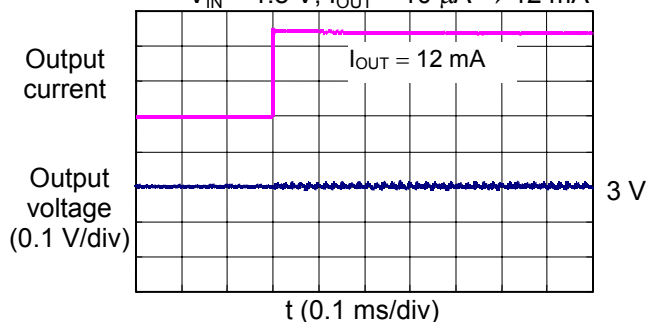
S-8351A50MC

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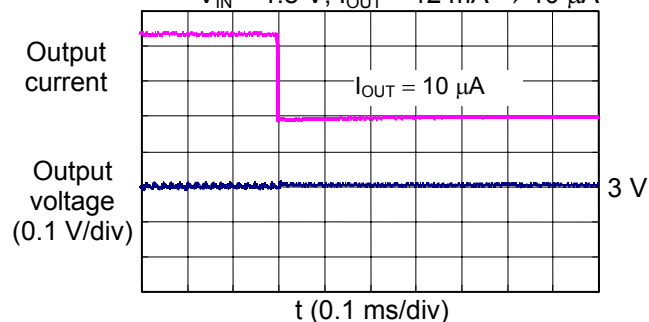
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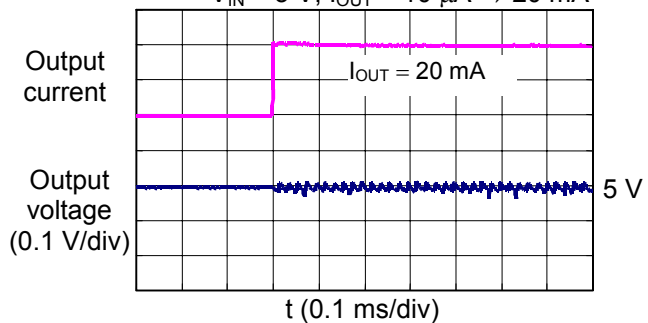
S-8352A30MC

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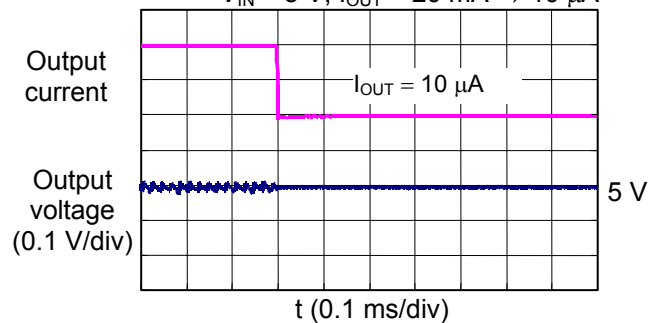
S-8352A30MC

 $V_{IN} = 1.8\text{ V}$, $I_{OUT} = 12\text{ mA} \rightarrow 10\text{ }\mu\text{A}$ 

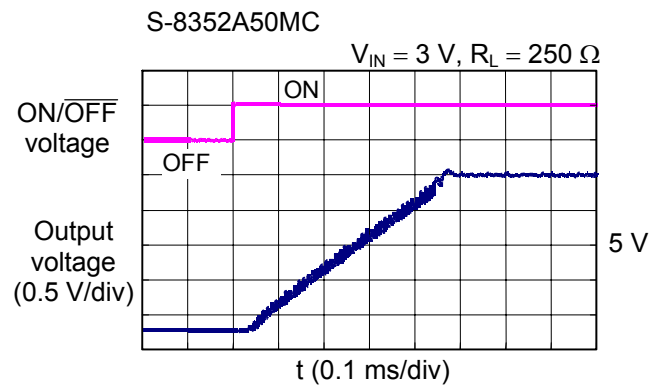
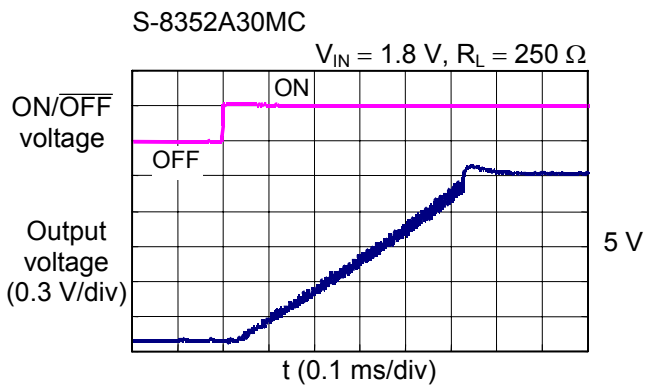
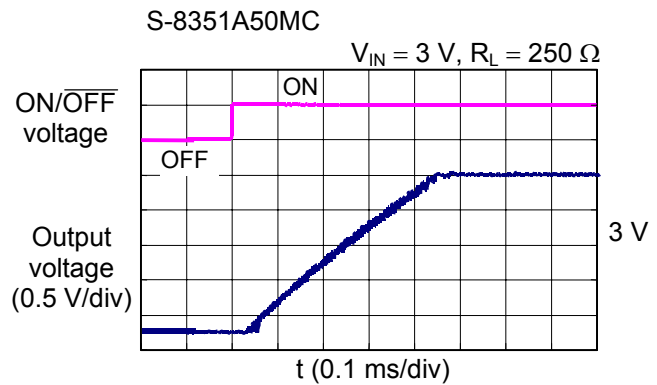
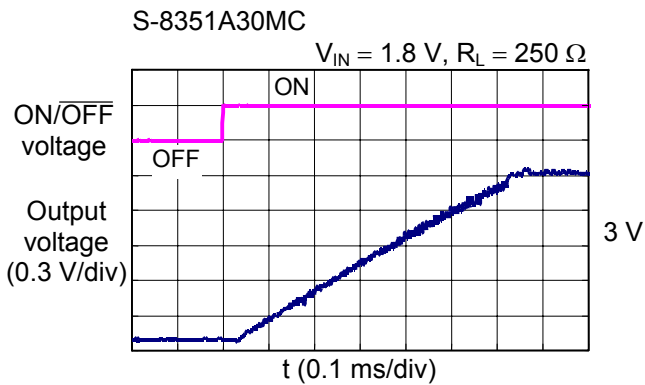
S-8352A50MC

 $V_{IN} = 3\text{ V}$, $I_{OUT} = 10\text{ }\mu\text{A} \rightarrow 20\text{ mA}$ 

S-8352A50MC

 $V_{IN} = 3\text{ V}$, $I_{OUT} = 20\text{ mA} \rightarrow 10\text{ }\mu\text{A}$ 

1.4 Shutdown pin response ($T_a = 25^\circ\text{C}$)



Reference Data (2)

The following shows the step-up characteristics when the coils in the table below are used for reference.

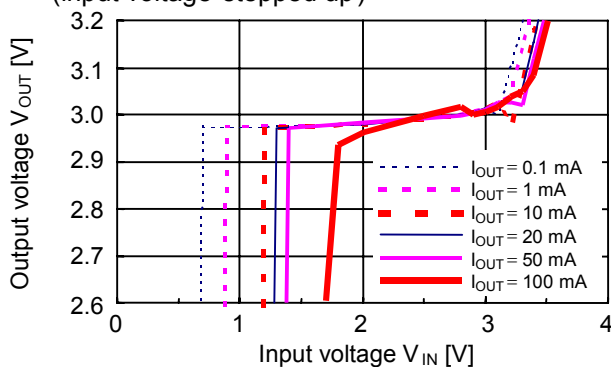
Table 4

Model	Manufacturer	L Value	DC Resistance	Current Rating
CDRH6D28-220	Sumida Corporation	22 μH	0.128 Ω	1200 mA
CDRH6D28-470	Sumida Corporation	47 μH	0.238 Ω	800 mA
CDRH6D28-101	Sumida Corporation	100 μH	0.535 Ω	540 mA
CDRH125-221	Sumida Corporation	220 μH	0.4 Ω	800 mA
CXLP120-470	Sumitomo Special Metals Co., Ltd	47 μH	0.95 Ω	450 mA
CXLP120-101	Sumitomo Special Metals Co., Ltd	100 μH	2.5 Ω	200 mA

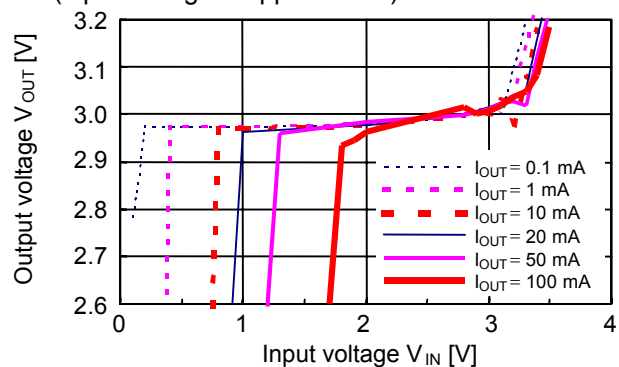
1. S-8351A30MC (built-in, $V_{OUT} = 3\text{ V}$)

1-1 CDRH6D28-470 (47 μH), $T_a = 25^\circ\text{C}$

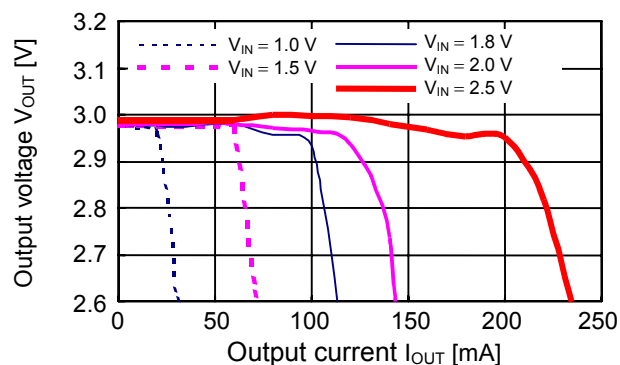
(a) Input voltage vs. Output voltage
(input voltage stepped up)



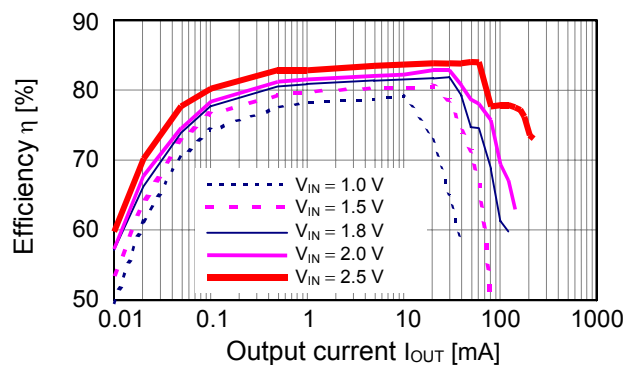
(b) Input voltage vs. Output voltage
(input voltage stepped down)



(c) Output current vs. Output voltage

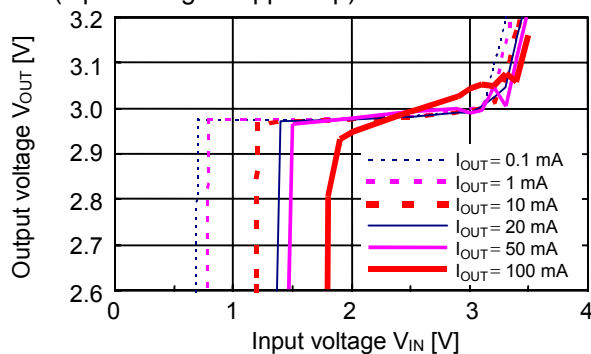


(d) Efficiency vs. Output current

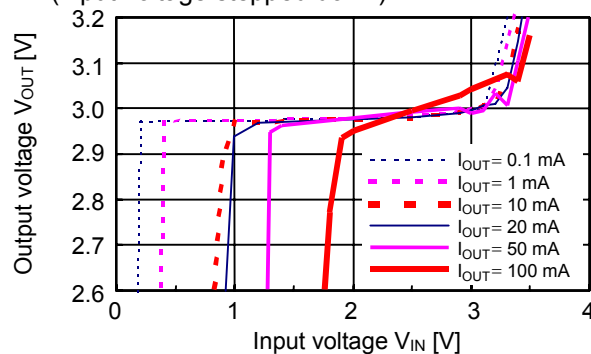


1-2 CDRH6D28-101 (100 μ H), $T_a = 25^\circ\text{C}$

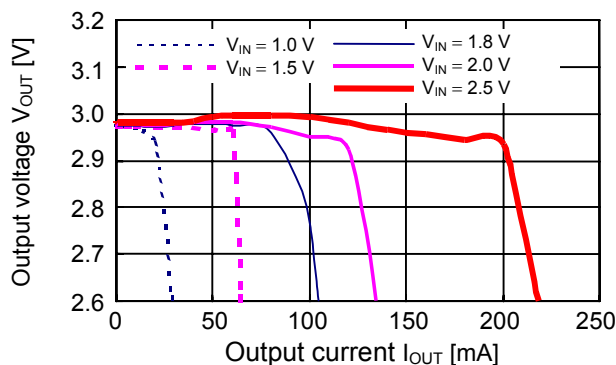
(a) Input voltage vs. Output voltage
(input voltage stepped up)



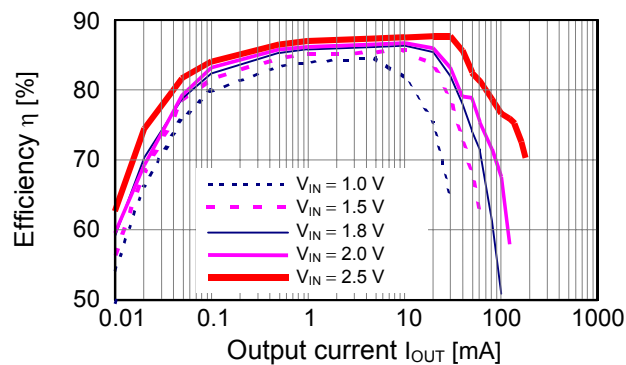
(b) Input voltage vs. Output voltage
(input voltage stepped down)



(c) Output current vs. Output voltage

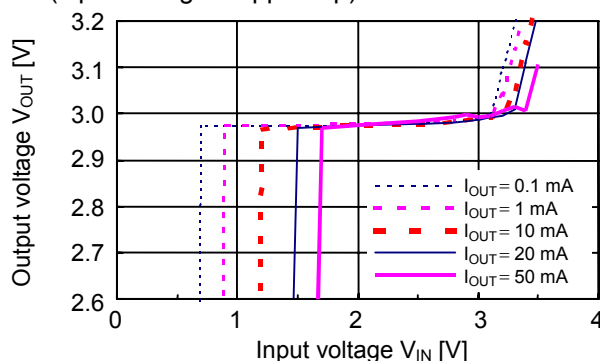


(d) Efficiency vs. Output current

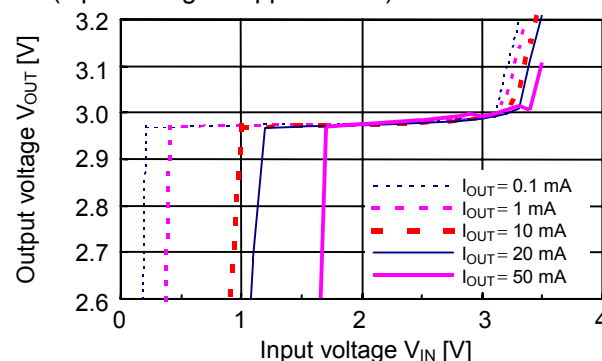


1-3 CXLP120-101 (100 μ H), $T_a = 25^\circ\text{C}$

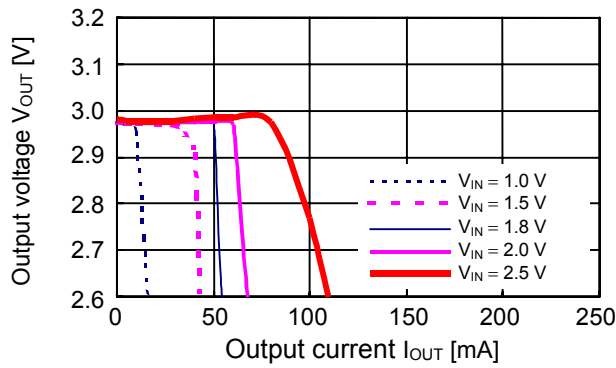
(a) Input voltage vs. Output voltage
(input voltage stepped up)



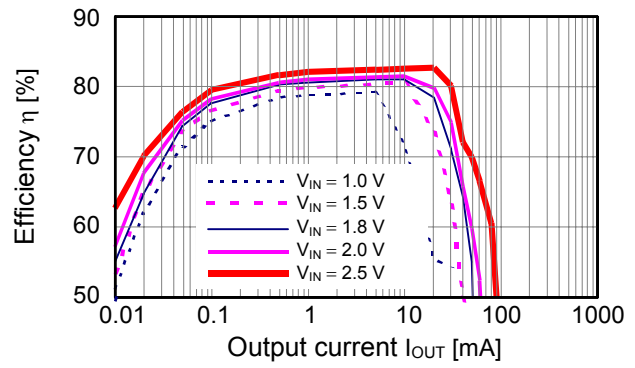
(b) Input voltage vs. Output voltage
(input voltage stepped down)



(c) Output current vs. Output voltage



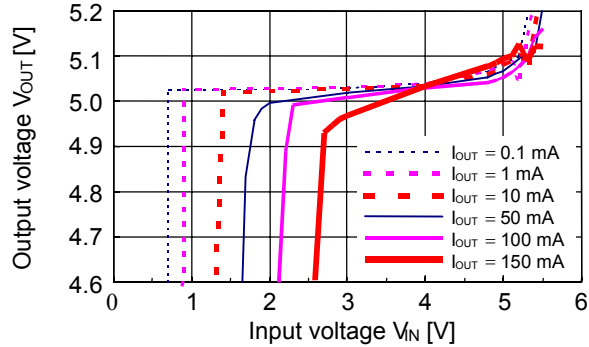
(d) Efficiency vs. Output current



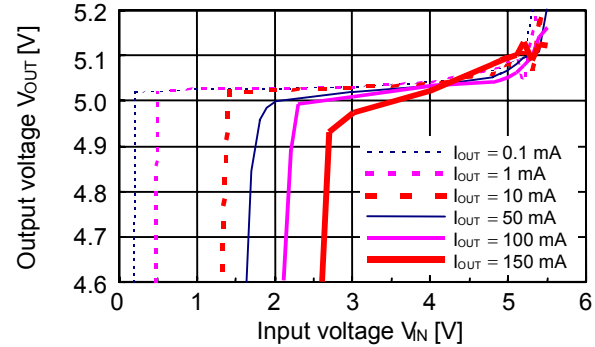
2. S-8351A50MC (built-in, $V_{OUT} = 5\text{ V}$)

2-1 CDRH6D28-101 (100 μH), $T_a = 25^\circ\text{C}$

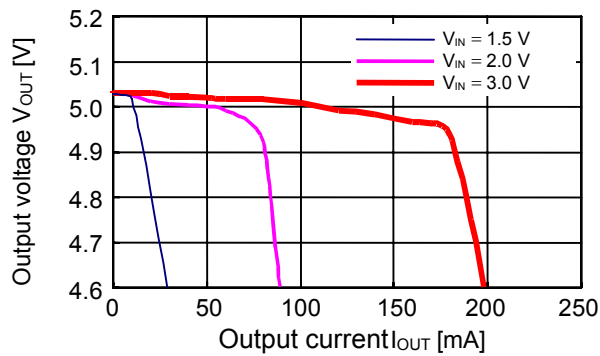
(a) Input voltage vs. Output voltage
(input voltage stepped up)



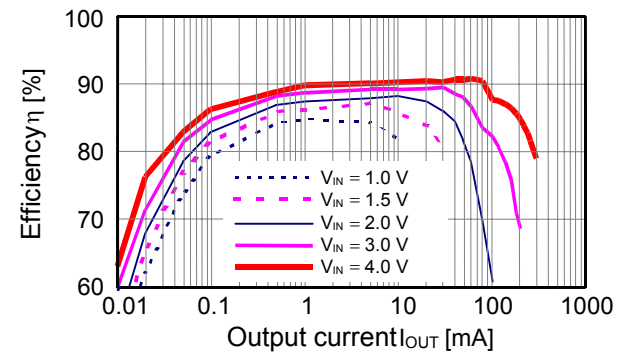
(b) Input voltage vs. Output voltage
(input voltage stepped down)



(c) Output current vs. Output voltage

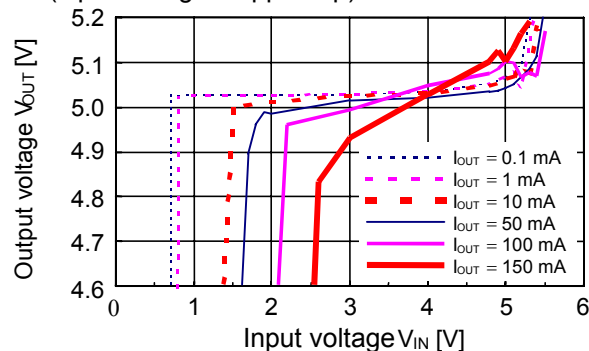


(d) Efficiency vs. Output current

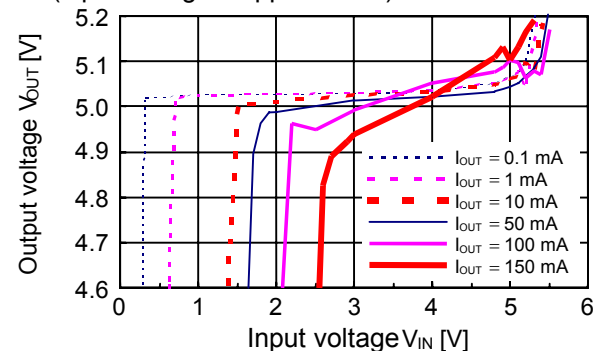


2-2 CDRH125-221 (220 μH), $T_a = 25^\circ\text{C}$

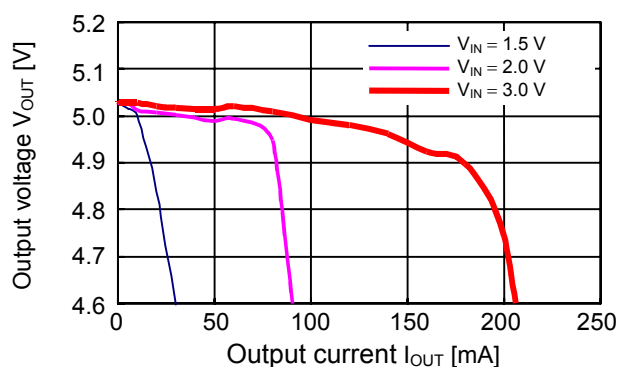
(a) Input voltage vs. Output voltage
(input voltage stepped up)



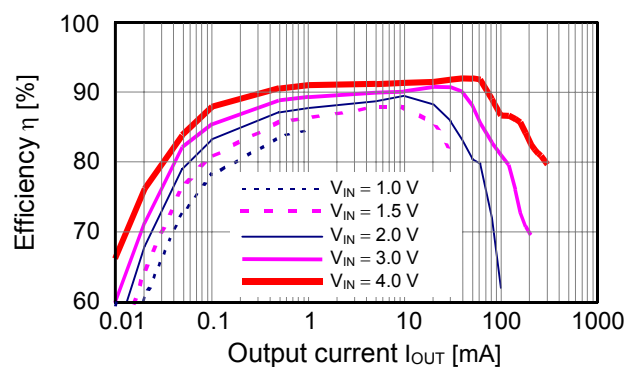
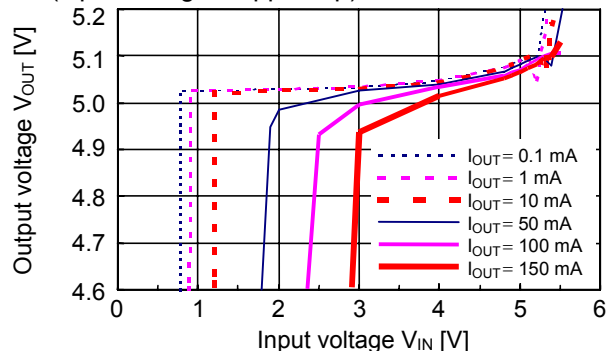
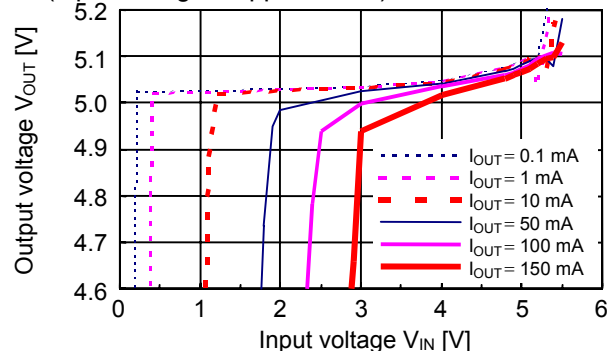
(b) Input voltage vs. Output voltage
(input voltage stepped down)



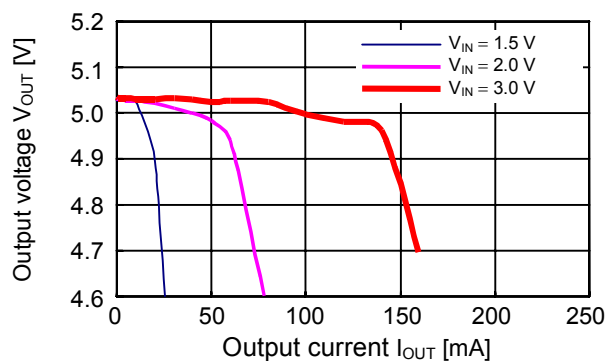
(c) Output current vs. Output voltage



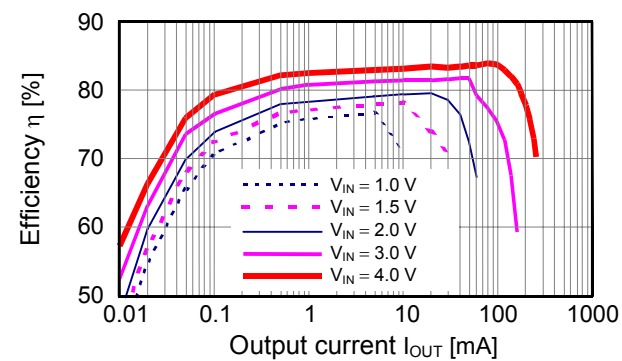
(d) Efficiency vs. Output current

2-3 CXLP120-470 (47 μ H), $T_a = 25^\circ\text{C}$ (a) Input voltage vs. Output voltage
(input voltage stepped up)(b) Input voltage vs. Output voltage
(input voltage stepped down)

(c) Output current vs. Output voltage



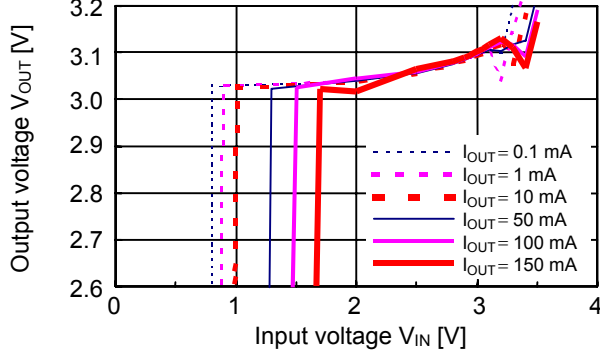
(d) Efficiency vs. Output current



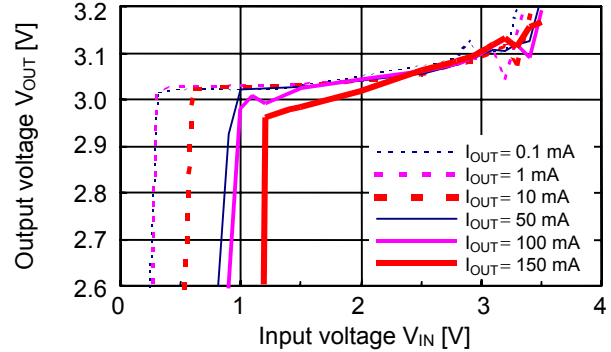
3. S-8352A30MC (external, $V_{OUT} = 3\text{ V}$)

3-1 CDRH6D28-220 (22 μH), $T_a = 25^\circ\text{C}$

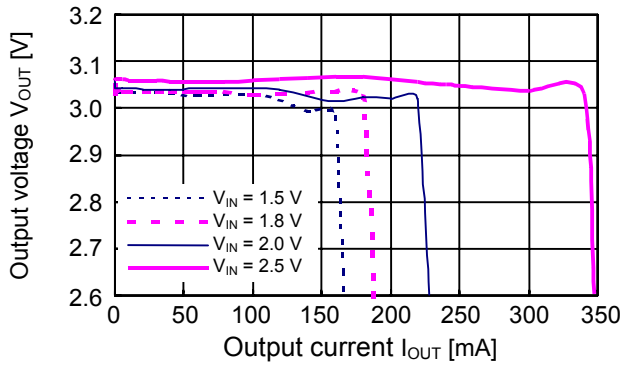
(a) Input voltage vs. Output voltage
(input voltage stepped up)



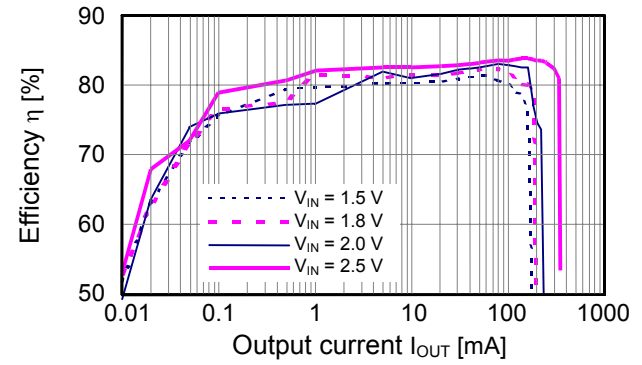
(b) Input voltage vs. Output voltage
(input voltage stepped down)



(c) Output current vs. Output voltage

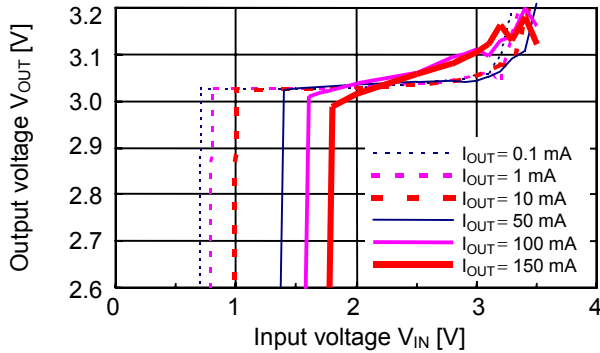


(d) Efficiency vs. Output current

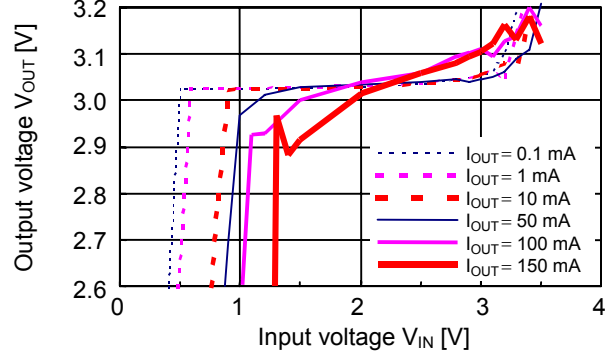


3-2 CDRH6D28-101 (100 μH), $T_a = 25^\circ\text{C}$

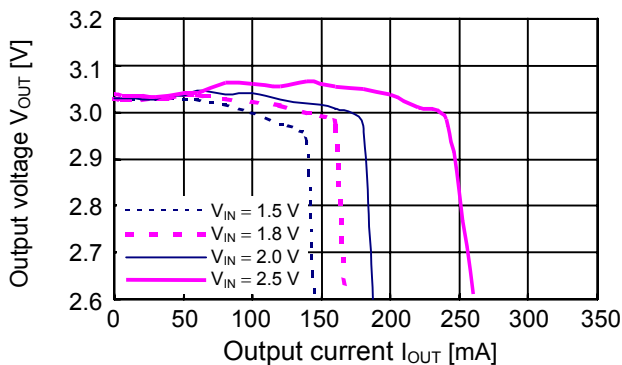
(a) Input voltage vs. Output voltage
(input voltage stepped up)



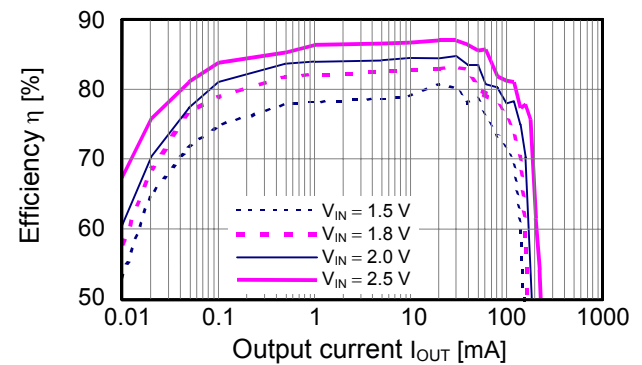
(b) Input voltage vs. Output voltage
(input voltage stepped down)

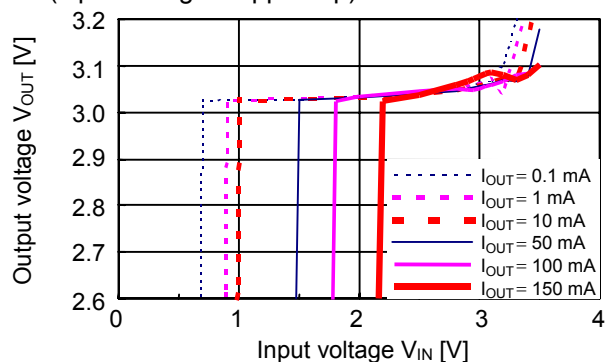
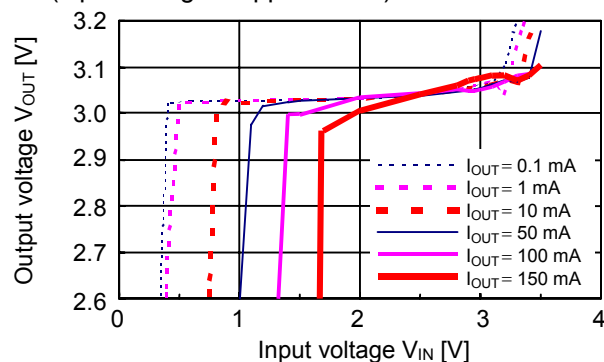


(c) Output current vs. Output voltage

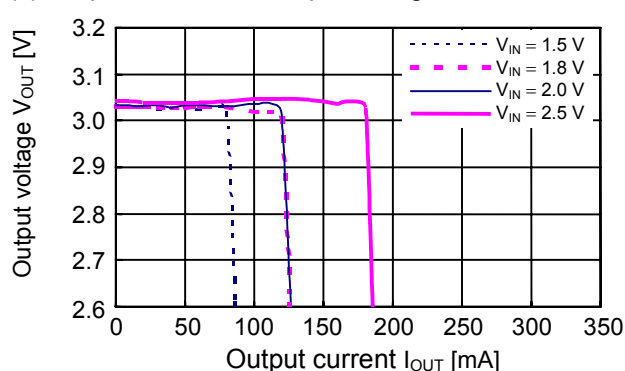


(d) Efficiency vs. Output current

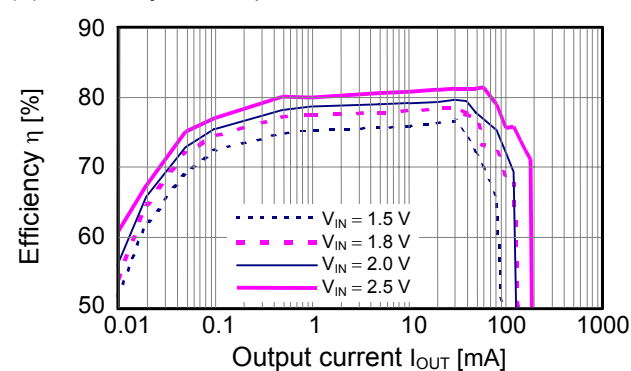
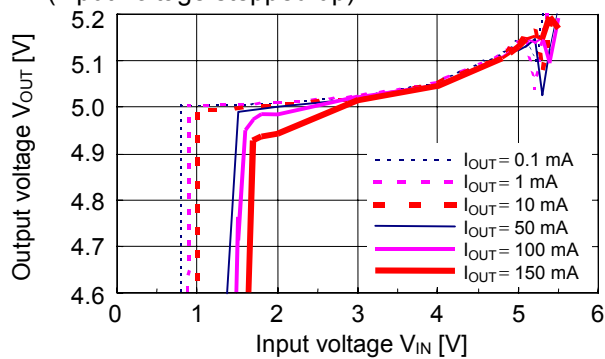
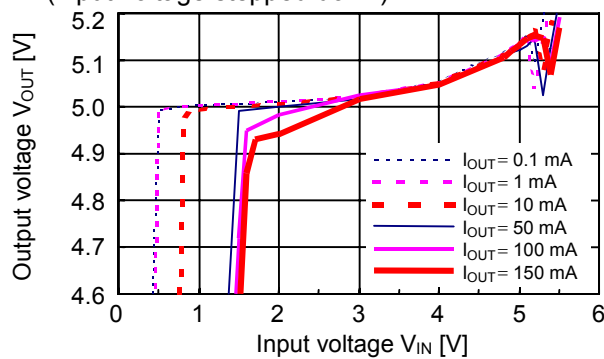


3-3 CXLP120-470 (47 μ H), $T_a = 25^\circ\text{C}$ (a) Input voltage vs. Output voltage
(input voltage stepped up)(b) Input voltage vs. Output voltage
(input voltage stepped down)

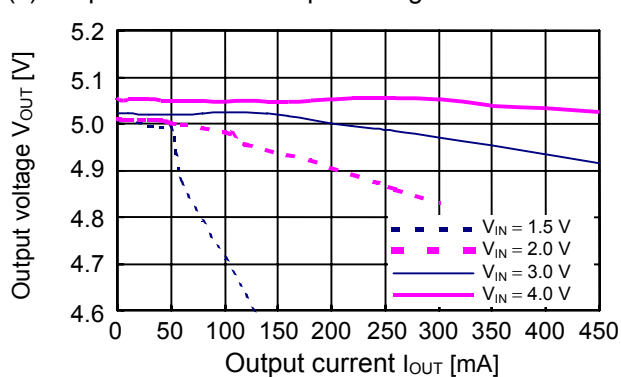
(c) Output current vs. Output voltage



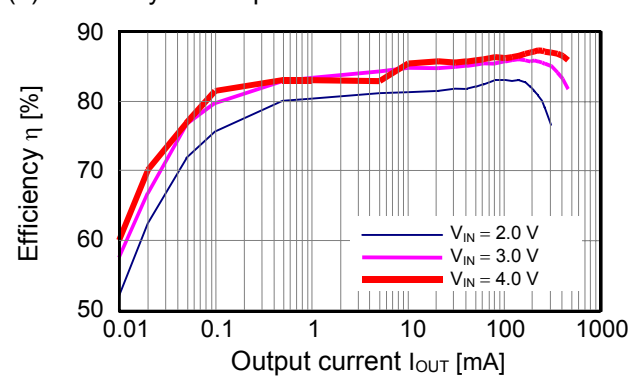
(d) Efficiency vs. Output current

**4. S-8352A50MC (external, $V_{OUT} = 5\text{ V}$)**4-1 CDRH6D28-220 (22 μ H), $T_a = 25^\circ\text{C}$ (a) Input voltage vs. Output voltage
(input voltage stepped up)(b) Input voltage vs. Output voltage
(input voltage stepped down)

(c) Output current vs. Output voltage

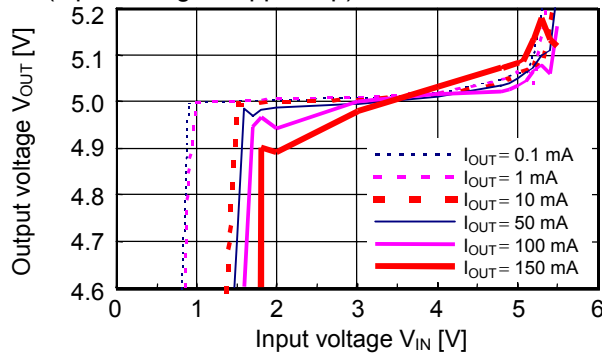


(d) Efficiency vs. Output current

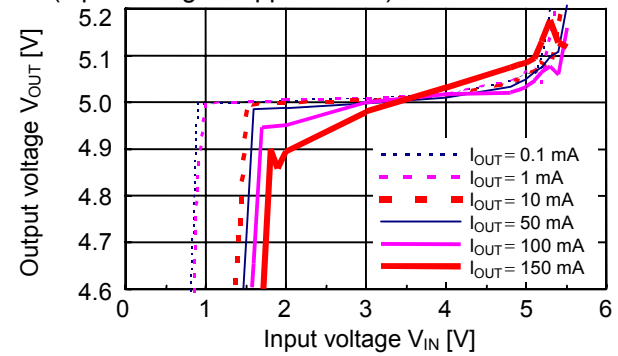


4-2 CDRH6D28-101 (100 μ H), $T_a = 25^\circ\text{C}$

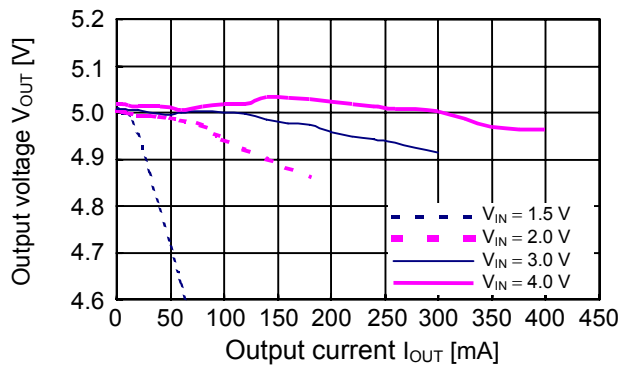
(a) Input voltage vs. Output voltage
(input voltage stepped up)



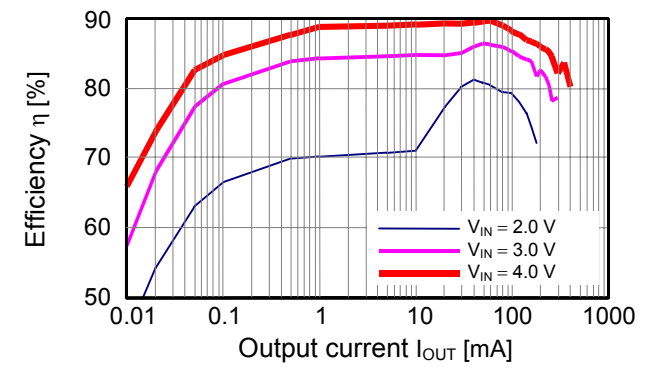
(b) Input voltage vs. Output voltage
(input voltage stepped down)



(c) Output current vs. Output voltage

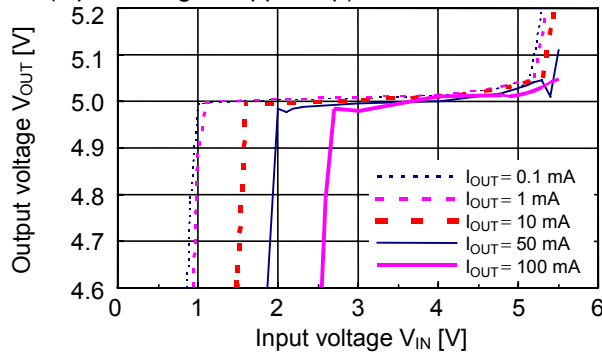


(d) Efficiency vs. Output current

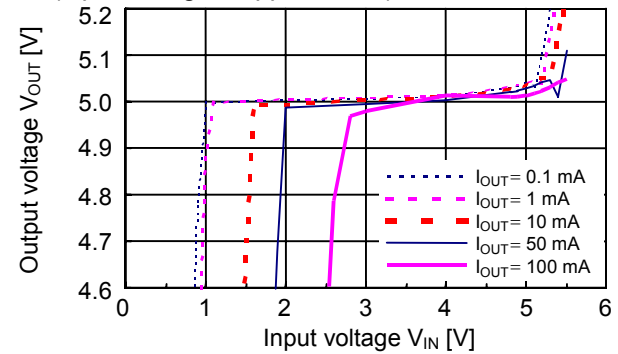


4-3 CXLP120-101 (100 μ H), $T_a = 25^\circ\text{C}$

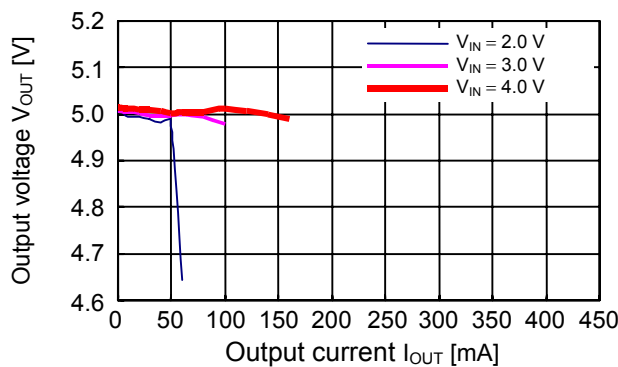
(a) Input voltage vs. Output voltage
(input voltage stepped up)



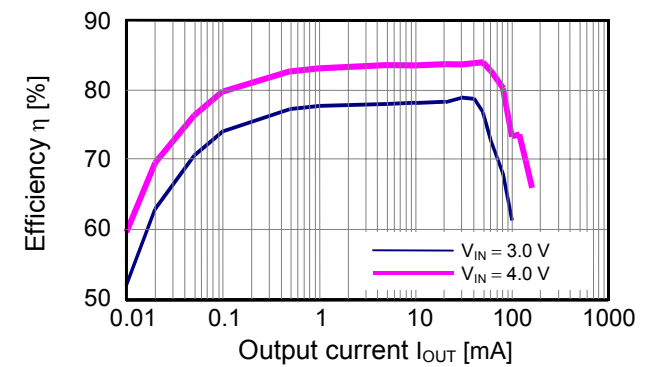
(b) Input voltage vs. Output voltage
(input voltage stepped down)



(c) Output current vs. Output voltage



(d) Efficiency vs. Output current

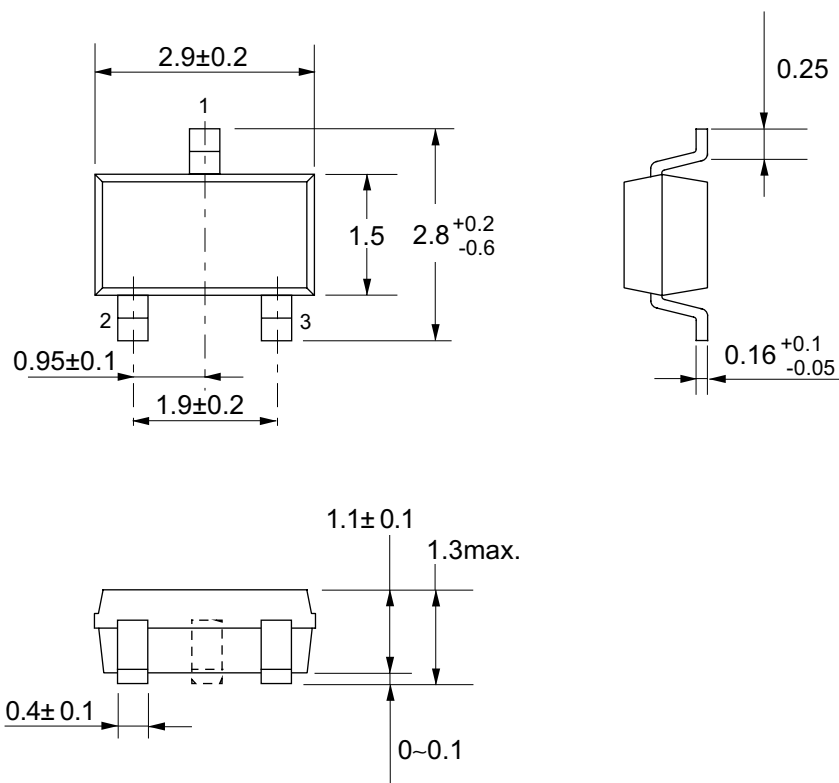


■ SOT-23-3

MP003-A 990531

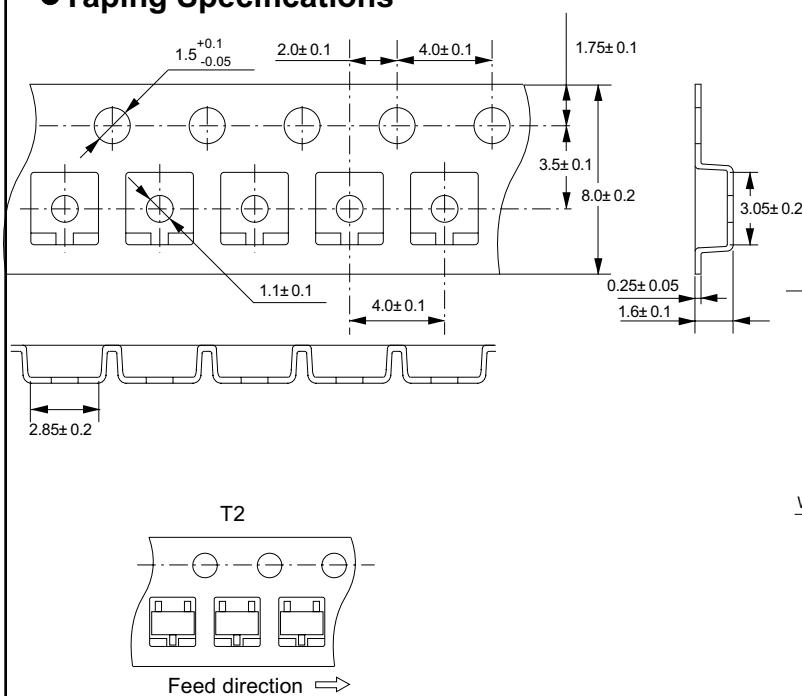
●Dimensions

Unit:mm



No.:MP003-A-P-SD-1.0

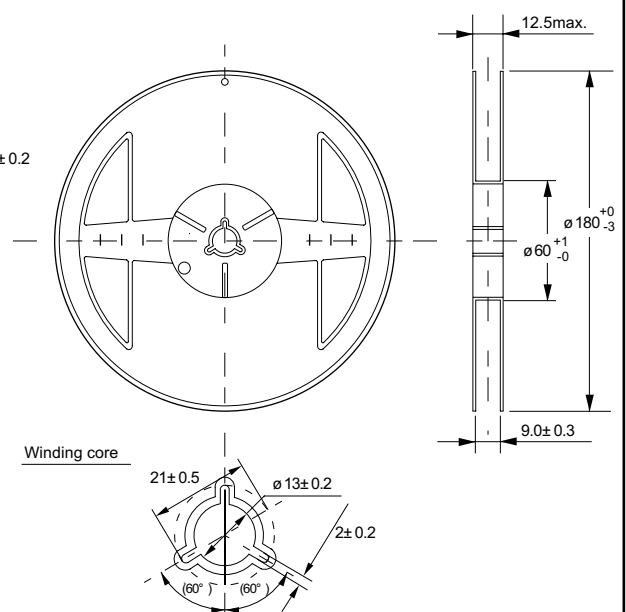
●Taping Specifications



No.:MP003-A-C-SD-1.0

●Reel Specifications

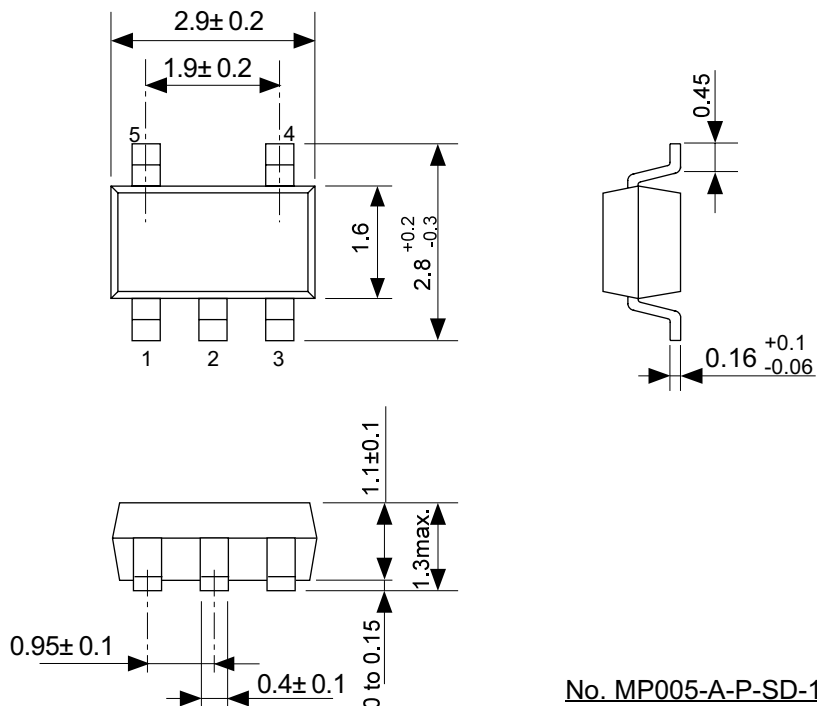
1 reel holds 3000 ICs.



No.:MP003-A-R-SD-1.0

● Dimensions

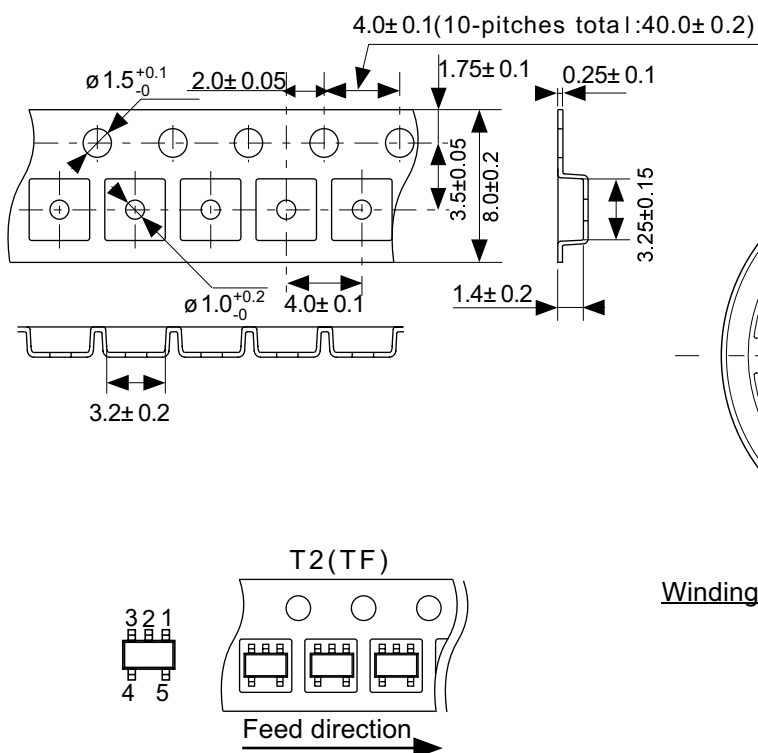
Unit : mm



No. MP005-A-P-SD-1.1

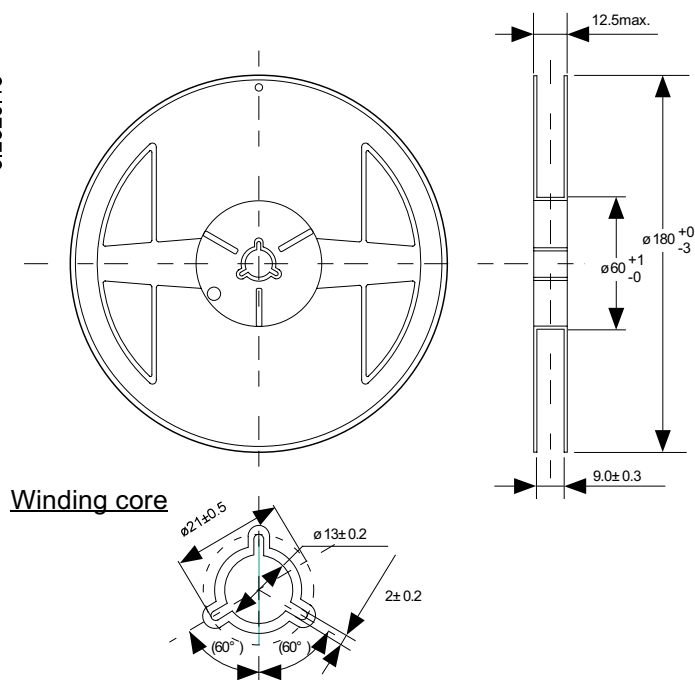
● Tape Specifications

● Reel Specifications



No. : MP005-A-C-SD-2.0

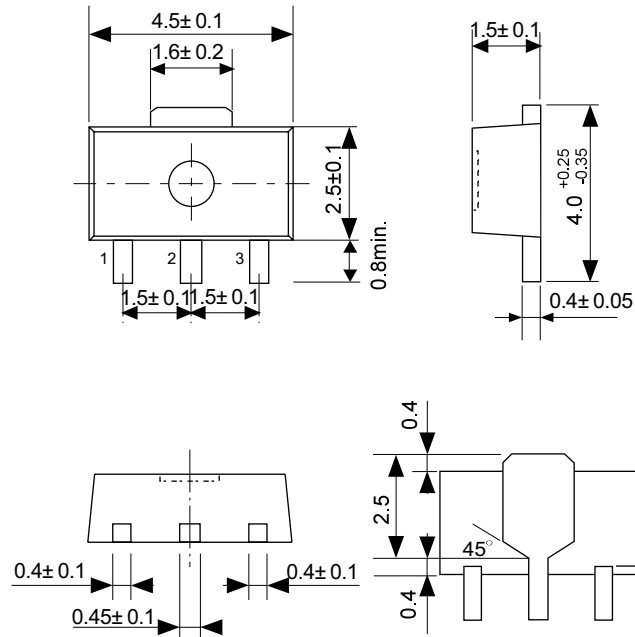
3000 pcs./reel



No. MP005-A-R-SD-1.0

●Dimensions

Unit:mm

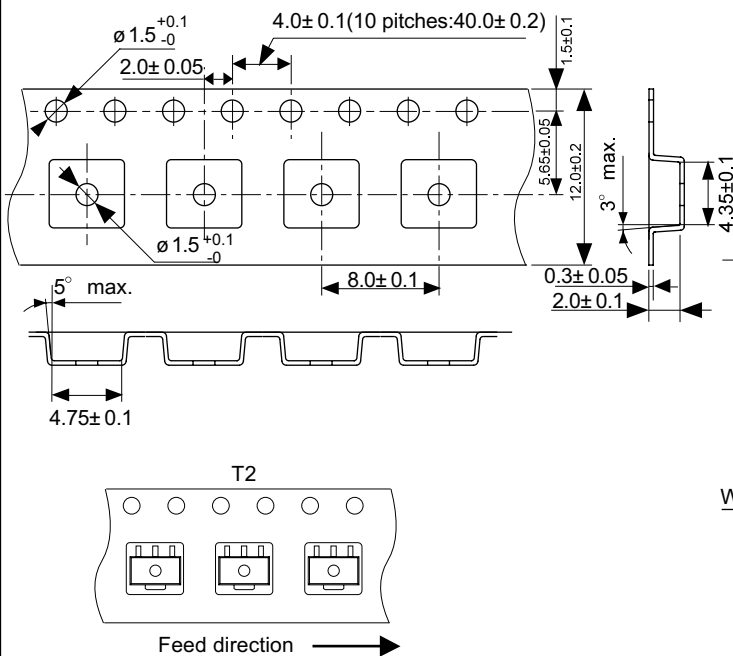


No. UP003-A-P-SD-1.0

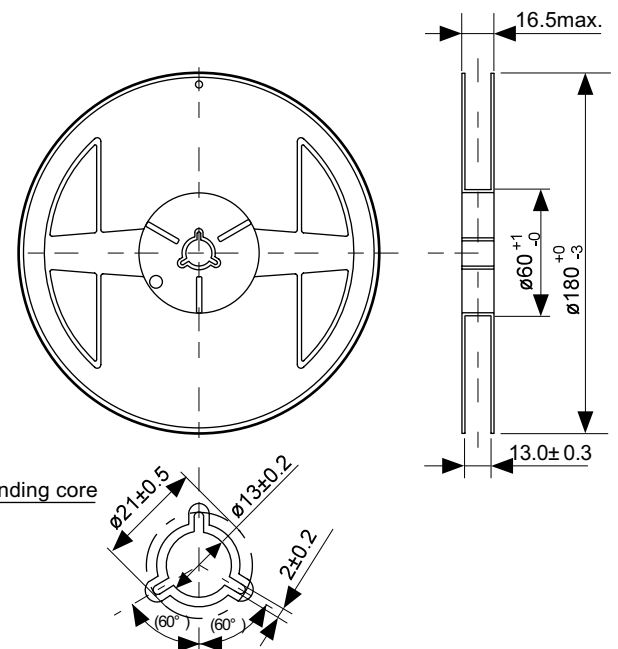
●Taping Specifications

●Reel Specifications

1 reel holds 1000 ICs.



No. UP003-A-C-SD-1.0



No. UP003-A-R-SD-1.0

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