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New Japan Radio Co.,Ltd.

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## LOW POWER SWITCHING REGULATOR

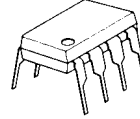
### ■ GENERAL DESCRIPTION

The NJM2352 is the industry's first monolithic low power switching regulators available in an 8-lead mini-DIP, and designed specifically for battery operated instruments. They each contain a 1.3V temperature compensated bandgap reference, adjustable free running oscillator, voltage comparator, low battery detection circuitry, and a 200mA switch transistor with all of the functions required to make a complete low power switching regulator.

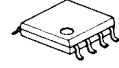
These regulators can achieve up to 80% efficiency in most applications while being able to operate over a wide input supply voltage range, 2.6V to 24V at a very low quiescent drain of 280μA.

The NJM2352 can be used as a building block in three basic applications : step-up, step-down and inverting.

### ■ PACKAGE OUTLINE



**NJM2352D**

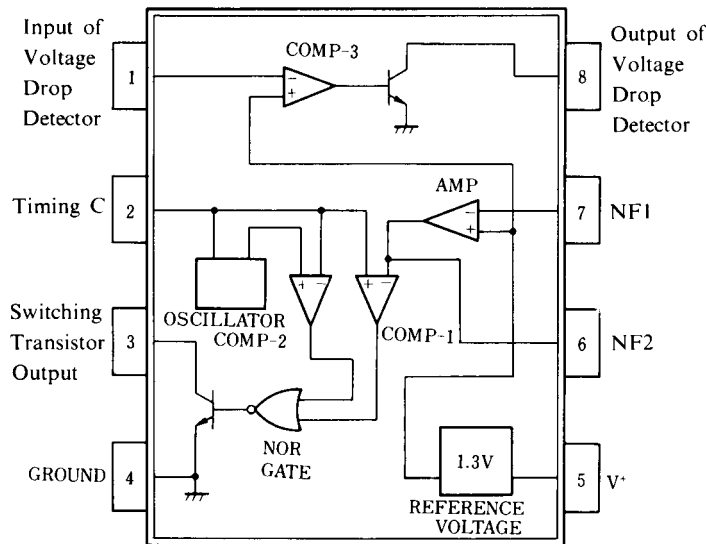


**NJM2352M**

### ■ FEATURES

- Operating Voltage (2.6V to 24.0V)
- Low Operating Current
- Internal Low Voltage Detect Circuit
- Pulse Width Modulation Control Circuit
- Package Outline                   DIP8, DMP8
- Bipolar Technology

### ■ BLOCK DIAGRAM



**NJM2352D**  
**NJM2352M**

# NJM2352

## ■ ABSOLUTE MAXIMUM RATINGS

(Ta = 25°C)

| PARAMETER                   | SYMBOL           | RATINGS                  | UNIT     |
|-----------------------------|------------------|--------------------------|----------|
| Supply Voltage              | V <sup>+</sup>   | 24                       | V        |
| Power Dissipation           | P <sub>D</sub>   | (DIP8) 500<br>(DMP8) 300 | mW<br>mW |
| Operating Temperature Range | T <sub>opr</sub> | -40 to +85               | °C       |
| Storage Temperature Range   | T <sub>stg</sub> | -40 to +125              | °C       |

## ■ ELECTRICAL CHARACTERISTICS

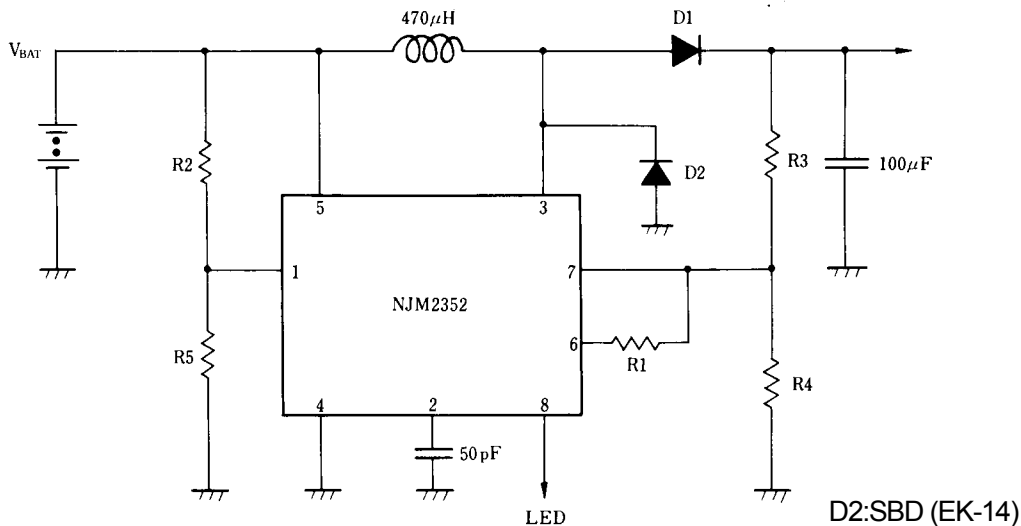
DC Electrical Characteristics (V<sup>+</sup> = 6V, Ta = 25°C)

| PARAMETER                          | SYMBOL               | TEST CONDITION                                     | MIN. | TYP. | MAX. | UNIT |
|------------------------------------|----------------------|--|------|------|------|------|
| Operating Current (1)              | I <sub>CC</sub> (1)  |  | -    | 275  | 350  | μA   |
| Operating Current (2)              | I <sub>CC</sub> (2)  | V <sup>+</sup> = 24V                               | -    | 400  | 550  | μA   |
| Reference Voltage                  | V <sub>REF</sub>     |  | 1.24 | 1.31 | 1.38 | V    |
| Sw. Saturation Voltage             | V <sub>SW</sub>      | I <sub>SW</sub> = 100mA                            | -    | 0.2  | 0.4  | V    |
| Sw. Current                        | I <sub>SW</sub>      | V <sub>SW</sub> = 0.4V                             | 100  | 200  | -    | mA   |
| Sw. Leakage Current                | I <sub>SWO</sub>     | V <sub>ⓐPIN</sub> = 24V                            | -    | 0.1  | 10   | μA   |
| Operating Frequency                | F <sub>O</sub>       | C <sub>X</sub> = 50pF                              | 40   | 50   | 60   | kHz  |
| Low Battery Output Current         | I <sub>LED</sub> (L) | V <sub>ⓐPIN</sub> = 1.1V, V <sub>ⓑPIN</sub> = 0.4V | 300  | 800  | -    | μA   |
| Low Battery Output Leakage Current | I <sub>LED</sub> (H) | V <sub>ⓐPIN</sub> = 1.4V, V <sub>ⓑPIN</sub> = 6V   | -    | 0.1  | 5    | μA   |

AC Electrical Characteristics (STEP-UP, Ta = 25°C)

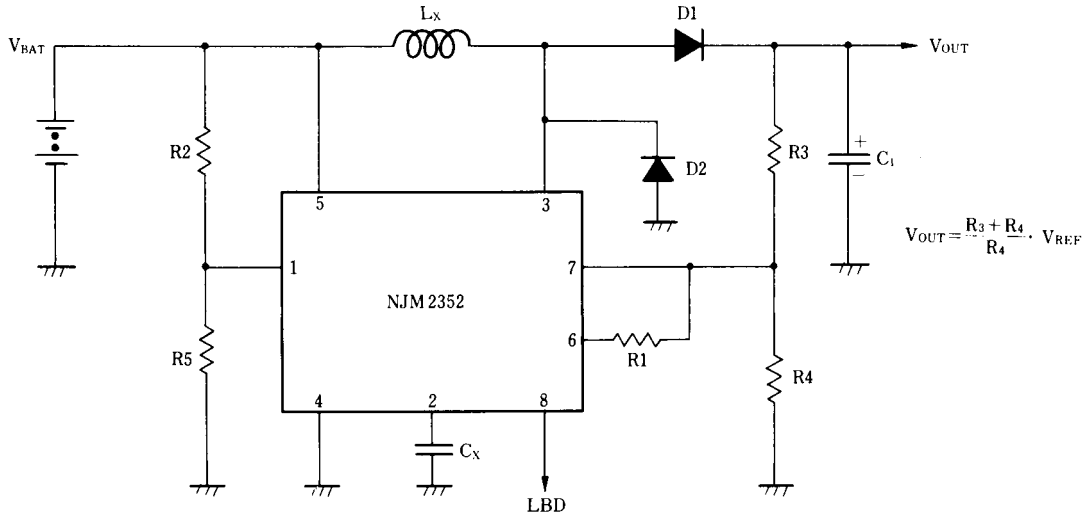
| PARAMETER                | SYMBOL                             | TEST CONDITION                                       | MIN. | TYP. | MAX. | UNIT |
|--------------------------|------------------------------------|--|------|------|------|------|
| Output Voltage (9V Set)  | V <sub>O(9)</sub>                  | V <sup>+</sup> = 4.5V, I <sub>O</sub> = 10mA         | 8.51 | 9.00 | 9.49 | V    |
| Load Regulation (9V Set) | ΔV <sub>O-I<sub>O</sub></sub> (9)  | V <sup>+</sup> = 4.5V, I <sub>O</sub> = 2 to 17mA    | -    | 100  | 200  | mV   |
| Line Regulation (9V Set) | ΔV <sub>O-V<sub>IN</sub></sub> (9) | V <sup>+</sup> = 4.5V to 8.1V, I <sub>O</sub> = 10mA | -    | 50   | 200  | mV   |
| Output Voltage (5V Set)  | I <sub>LED</sub> (L)               | V <sup>+</sup> = 2.6V, I <sub>O</sub> = 10mA         | 4.72 | 5.00 | 5.28 | V    |
| Output Voltage (24V Set) | I <sub>LED</sub> (H)               | V <sup>+</sup> = 12V, I <sub>O</sub> = 4mA           | 22.7 | 24.0 | 25.3 | V    |

## ■ TEST CIRCUIT

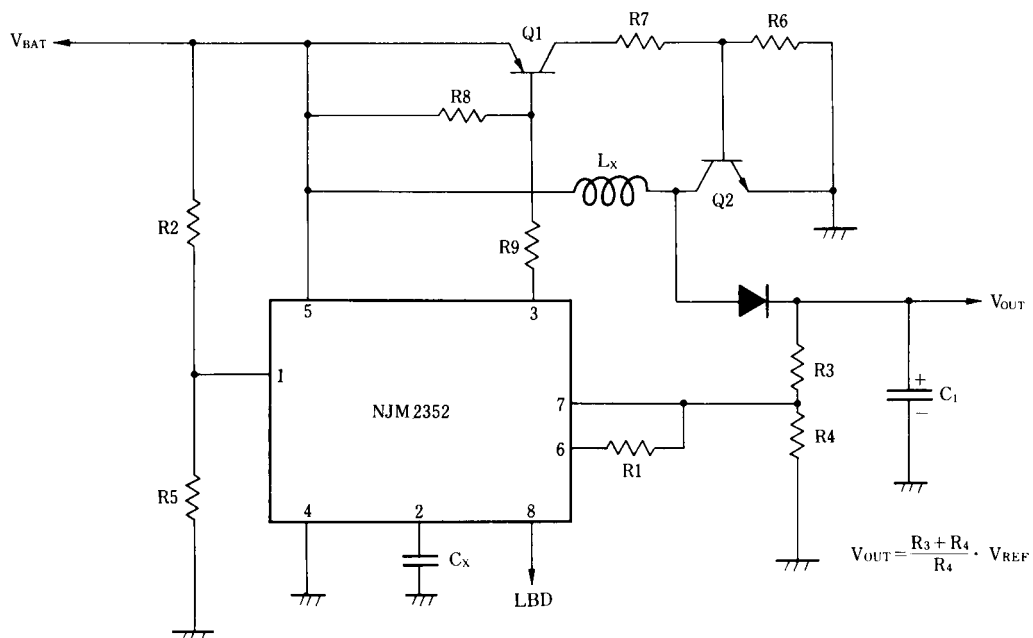


## ■ TYPICAL APPLICATION

### 1. Step-Up Switching Regulator (Low Current)

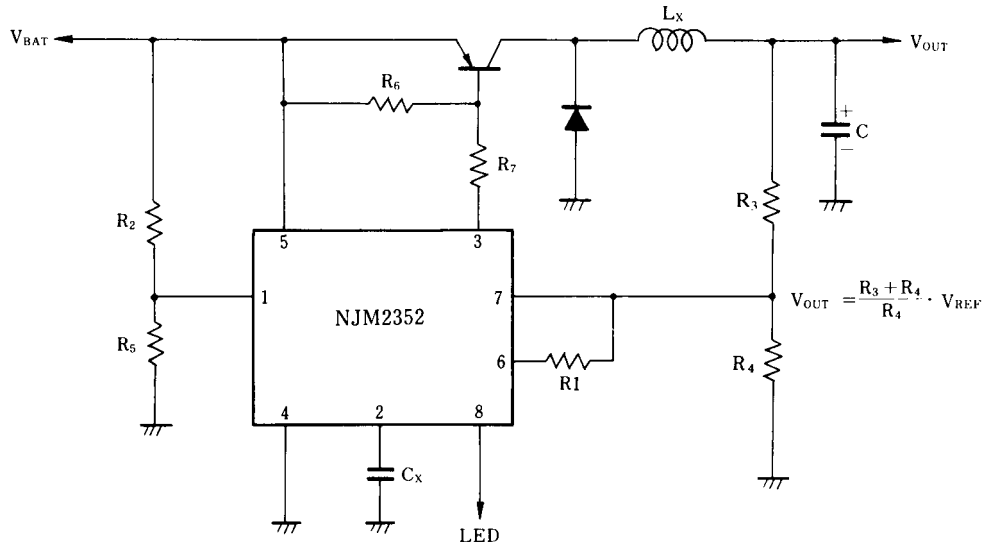


### 2. Step-Up Switching Regulator (High Current)

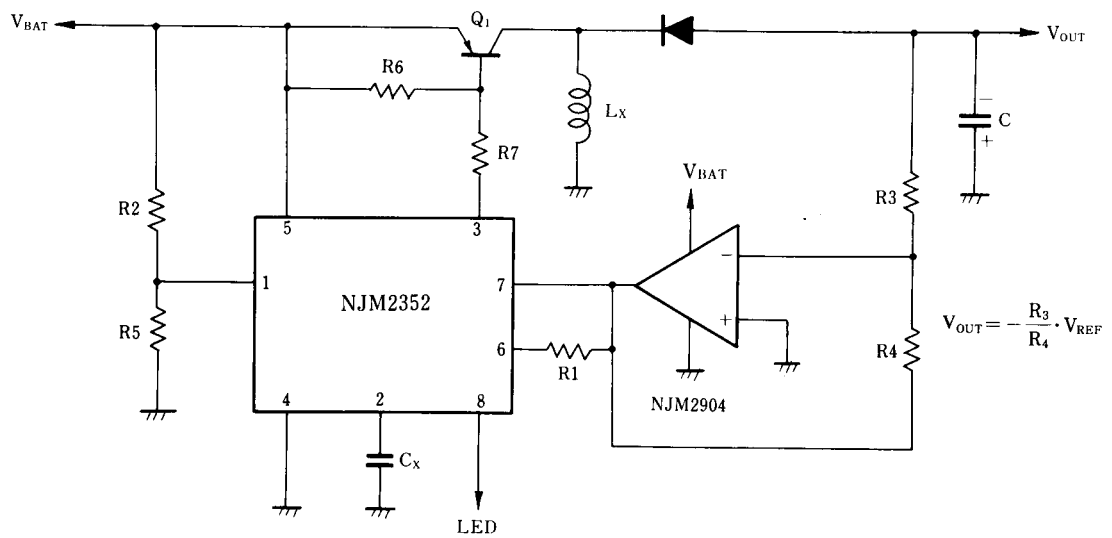


## ■ TYPICAL APPLICATION

### 3. Step-Down Switching Regulator



### 4. Inverting Switching Regulator



## ■ DESIGN EQUATIONS

| Component           | Step Up  | Step Down  | Inverting  |
|---------------------|--|--|--|
| R <sub>1</sub>      | $R_1=R_3 \times 10$  | $R_1=R_3 \times 10$                              | $R_1=R_3 \times 10$  |
| R <sub>2</sub>      | $\frac{V_{TH} - V_{REF}}{5\mu A}$  | $\frac{V_{TH} - V_{REF}}{5\mu A}$                | $\frac{V_{TH} - V_{REF}}{5\mu A}$  |
| R <sub>3</sub>      | $\frac{V_{OUT} - V_{REF}}{I_1}$  | $\frac{V_{OUT} - V_{REF}}{I_1}$                  | $\frac{V_{OUT}}{I_1}$  |
| R <sub>4</sub>      | $\frac{V_{REF}}{I_1}$  | $\frac{V_{REF}}{I_1}$                            | $\frac{V_{REF}}{I_1}$  |
| R <sub>5</sub>      | 261Ω   | 261Ω   | 261Ω   |
| C <sub>x</sub> (pF) | $\frac{2.14 \times 10^6}{F_O(\text{Hz})}$  | $\frac{2.14 \times 10^6}{F_O}$                   | $\frac{2.14 \times 10^6}{F_O}$   |
| L <sub>x</sub>      | $\frac{0.3 \cdot V_{BAT} \cdot (V_{OUT} - V_{BAT})}{F_O \cdot I_{LOAD} \cdot V_{OUT}}$   | $\frac{0.3 \cdot (V_{OUT})}{F_O \cdot I_{LOAD}}$ | $\frac{0.3 \cdot V_{BAT} \cdot  V_{OUT} }{F_O \cdot I_{LOAD} \cdot (V_{BAT} +  V_{OUT} )}$                           |
| C <sub>1</sub>      | $\frac{0.15 I_{LOAD} (2V_{OUT} - V_{BAT})^2}{F_O \cdot V_{OUT} \cdot V_R \cdot V_{BAT}}$ | $\frac{I_{LOAD}}{4F_O \cdot V_R}$                | $\frac{0.15 \cdot I_{LOAD} \cdot (V_{BAT} + 2 V_{OUT} )^2}{F_O \cdot V_{BAT} \cdot (V_{BAT} +  V_{OUT} ) \cdot V_R}$ |
| R <sub>6</sub>      | $\frac{35 \cdot V_{BAT}}{I_{LOAD} \cdot V_{OUT}}$  | $\frac{35}{I_{LOAD}}$                            | $\frac{35 \cdot V_{BAT}}{I_{LOAD} \cdot (V_{BAT} +  V_{OUT} )}$  |
| R <sub>7</sub>      | $\frac{5 \cdot (V_{BAT})^2}{I_{LOAD} \cdot V_{OUT}}$                                     | $\frac{5 \cdot V_{BAT}}{I_{LOAD}}$               | $\frac{5 \cdot (V_{BAT})^2}{I_{LOAD} \cdot (V_{BAT} +  V_{OUT} )}$   |
| R <sub>8</sub>      | $\frac{350 \cdot V_{BAT}}{I_{LOAD} \cdot V_{OUT}}$                                       |  |  |
| R <sub>9</sub>      | $\frac{50(V_{BAT})^2}{I_{LOAD} \cdot V_{OUT}}$   |  |  |

I<sub>1</sub> = 100μA

V<sub>TH</sub> : low battery detection voltage.

Ripple Voltage at V<sub>R</sub> : I<sub>1</sub> = 50 to 100μA.

# NJM2352

## DESCRIPTION

The NJM2352 is a micro-power switching regulator control IC suitable for a equipment of battery operation and may be used as step-up, step-down and inverting regulators.

The NJM2352 contains a reference, oscillator, amplifier, comparator, detector of input voltage drop and switching transistor. The output voltage is controled by PWM method.

The NJM2352 applies a bandgap as a reference voltage. The oscillator is composed of putting one capacitance (Cx) to the pin 2. The amplifier is 80dB open-loop voltage gain and 1MHz band width. By adding adequate resistors to the pin 1, the indicating signal comes when the input voltage drops more than designed input voltage. Switching transistor is open collector.

## TERMINAL DESCRIPTION

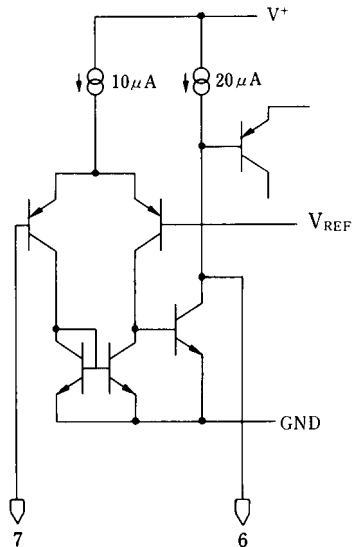
| TERMINAL NO. | TERMINAL ITEMS                  | FUNCTION   | INSIDE EQUIVALENT CIRCUITS |
|--------------|---------------------------------|--|----------------------------|
| 1            | Input of Voltage Drop Detector  | Inverting input Terminal of comparator-3.<br>When input voltage drops than non-inverting input voltage, comparator drives indicator output transistor. |                            |
| 8            | Output of Voltage Drop Detector | Open collector output transistor for driving LED, LCD etc.   |                            |

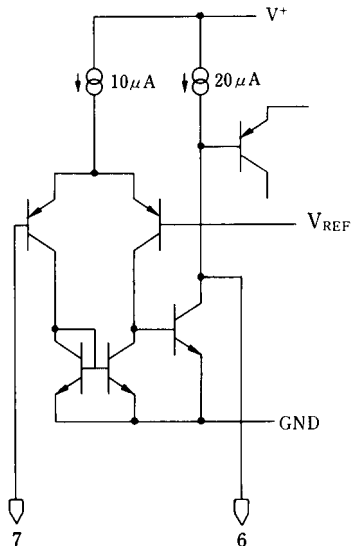
## ■ TERMINAL DESCRIPTION

| TERMINAL NO. | TERMINAL ITEMS              | FUNCTION   | INSIDE EQUIVALENT CIRCUITS   |
|--------------|-----------------------------|--|--|
| 2            | Timing C                    | Connecting timing for deciding oscillator frequency. | <p>The diagram shows two comparators, COMP-1 and COMP-2, with their non-inverting inputs connected to a common node. This node is also connected to a 10µA current source that draws current from the V+ supply. The outputs of the comparators are connected to a network of transistors that eventually leads to terminal 2. The other inputs of the comparators are connected to GND.</p>   |
| 3            | Switching Transistor Output | Open collector Output of switching transistor.       | <p>The diagram shows a switching transistor circuit. A NOR gate has one input connected to a 10µA current source and the other to a 200k resistor connected to V+. The output of the NOR gate is connected to the base of a transistor. The emitter of this transistor is connected to GND, and its collector is connected to V+ through a 1k resistor. The collector of this transistor is also connected to the base of a second transistor. The emitter of the second transistor is connected to GND through a 5k resistor, and its collector is connected to terminal 3.</p> |
| 4            | GROUND                      | Ground   |  |
| 5            | V <sup>+</sup>              | Supply voltage terminal.                             |  |



## ■ TERMINAL DESCRIPTION

| TERMINAL NO. | TERMINAL ITEMS | FUNCTION   | INSIDE EQUIVALENT CIRCUITS   |
|--------------|----------------|--|--|
| 6            | NF2            | Terminal from connecting point of AMP output and COMP-1 inverting input. |  |
| 7            | NF1            | Inverting input of amplifier.  |  |



## ■ PRINCIPLE OF OPERATION

The NJM2352 circuit block is shown on Fig. 1 and timing chart on Fig. 2. Function of COMP-2 is setting dead-time. At point A is the square wave and at point B is the triangular wave. By putting two input signals (A, B) into COMP-2, output (point C) voltage is held high level during rising period of triangular wave and the switching transistor is kept in the off condition regardless the COMP-1 output level. So the maximum duty cycle of the NJM2352 is 50%.

The COMP-1 makes on-time of switching transistor longer when the output voltage is high and shorter when it is low. Thus function of the COMP-1 is pulse wide modulation. When the AMP's output waveform is D, COMP-1 output is like E, and NOR GATE output becomes high level only when both inputs, C, E, are low, and so the falling period of triangular wave is the range of pulse width control.

Fig. 1

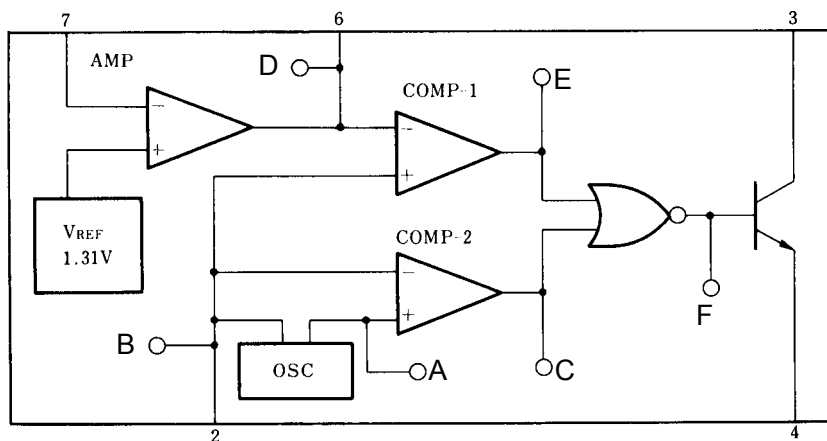
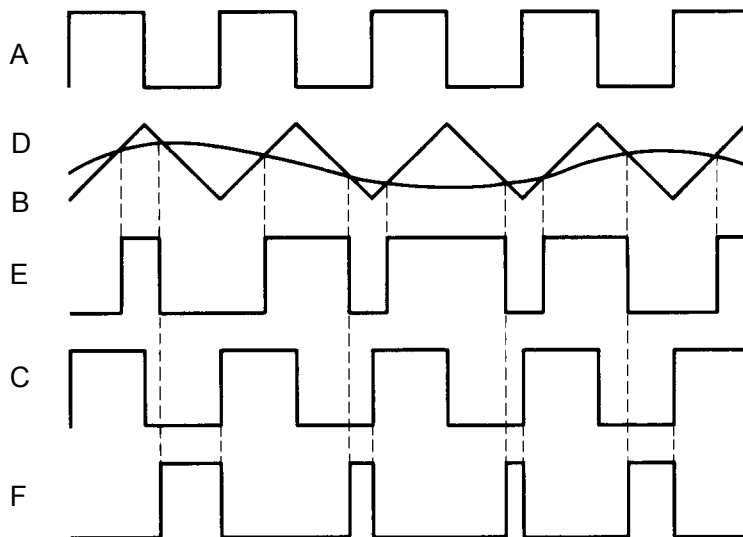


Fig. 2



## ■ MINIMUM OPERATING VOLTAGE

Minimum operating voltage is  $V^+ \geq 2.6V$  at  $25^\circ C$  and its temperature coefficient is negative. Be careful when you design. Less than this minimum operating voltage, internal switching transistor becomes on, and the surge-like high current flows into it especially in Step-Up or Inverting application.

## ■ OSCILLATOR

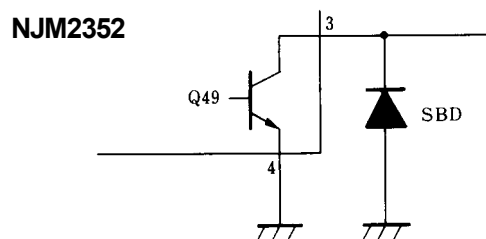
Oscillator frequency is decided by putting a capacitor into PIN 2. The amplitude of both square wave A and triangular wave B is between  $1 V_{BE}$  and  $3V_{BE}$ .

## ■ AMPLIFIER

AMP source current is  $20 \mu A$  max. and so the feedback resistor  $R_1$  to be connected to PIN 6 and PIN 7 are recommended more than  $100k\Omega$ .

## ■ SWITCHING TRANSISTOR

When the negative voltage more than  $0.5V$  absolute value based on ground level is applied, the NJM2352 may operate unordinary by reason of parasitic effect in it. And so put SBD in between PIN 3 and ground when you drive directory coil with internal switching transistor.

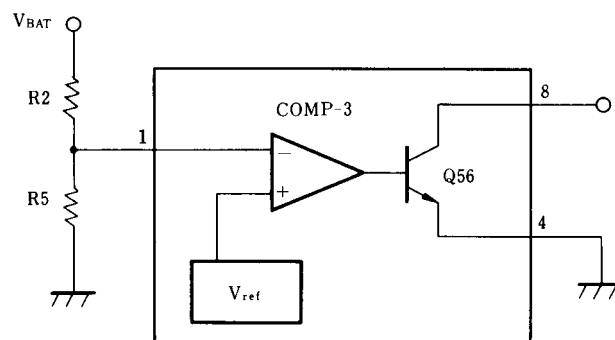


## ■ DETECTION CIRCUIT OF INPUT VOLTAGE DROP

When input voltage becomes lower than specified voltage, transistor  $Q_{56}$  switches on and indicative device like LED turns on. The specified voltage is decided by internal reference voltage and outer resistors ratio.

$$V_{TH} = V_{REF} (1 + R2/R5) + R2 \times 0.5\mu A$$

When - input voltage becomes lower than + input voltage, PIN 1 of COMP-3 sinks about  $1\mu A$  and thus prevents chattering. Transistor  $Q_{56}$  becomes off condition when PIN 1 voltage is lower than about  $0.2V$ . It is recommendable to put about  $1\mu F$  to PIN 1 in actual application to avoid switching noise.



## ■ EFFICIENCY

Efficiency is shown below.

$$\text{Set Up} = \frac{V_{IN} - V_S}{V_{IN}} \times \frac{V_{OUT}}{V_{OUT} + V_D - V_S}$$

$$\text{Step Down} = \frac{V_{IN} - V_S + V_D}{V_{IN}} \times \frac{V_{OUT}}{V_{OUT} + V_D}$$

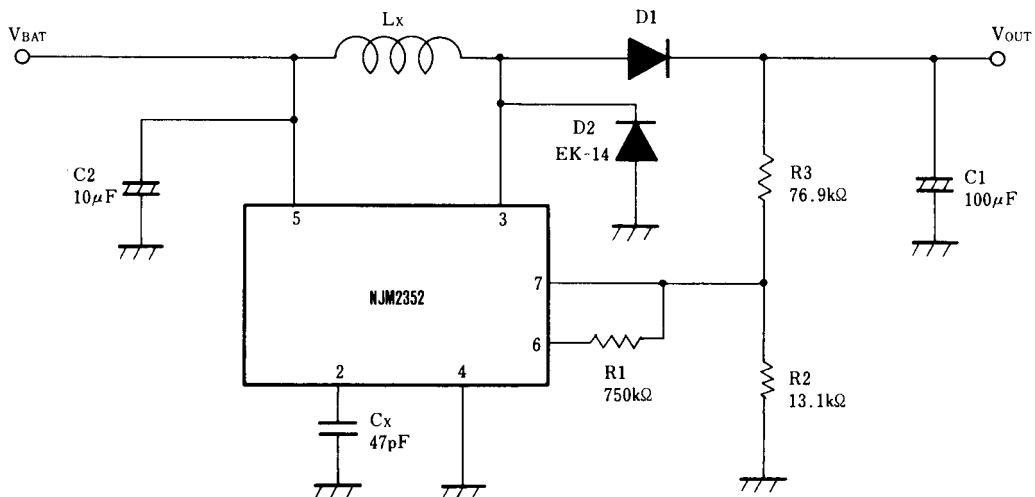
$$\text{Inverting} = \frac{V_{IN} - V_S}{V_{IN}} \times \frac{|V_{OUT}|}{|V_{OUT}| + V_D}$$

$V_S$  : Voltage Drop based on switching transistor On-Resistance.

$V_D$  : Diode Forward Voltage Drop.

If  $V_S$  and  $V_D$  are low, efficiency increase. Also speed of switching transistor and diode, series resistance of L will affect to it. Example is shown on typical characteristic graph.

## ■ TEST CIRCUIT 2 ( $V_{OUT}$ : 9V)

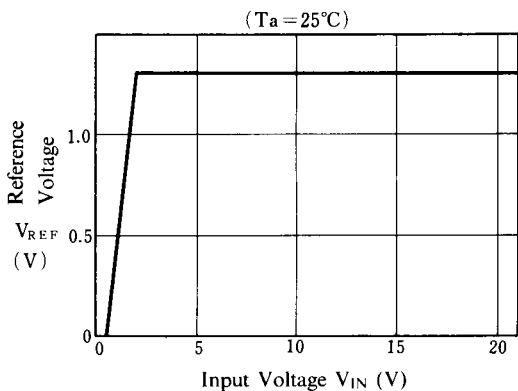


## ■ PARAMETER

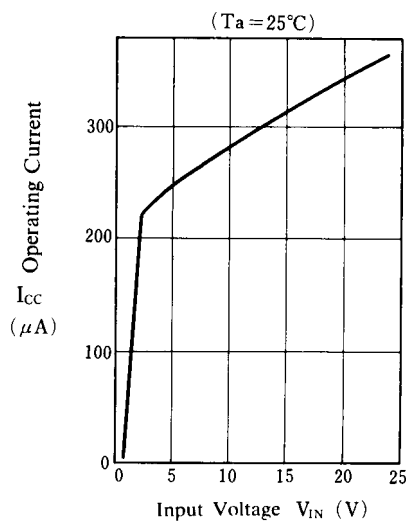
- D1  
EK-14  
IS1588
- LX = 470μH  
L1 : Ingermal Resistance = 0.2Ω  
L2 : Ingermal Resistance = 2Ω  
L3 : Ingermal Resistance = 7Ω

## ■ TYPICAL CHARACTERISTICS

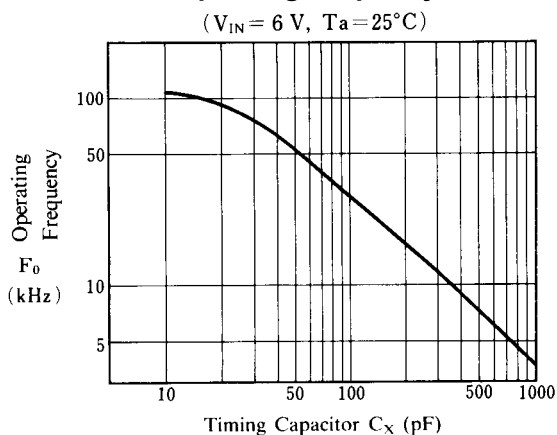
### Reference Voltage



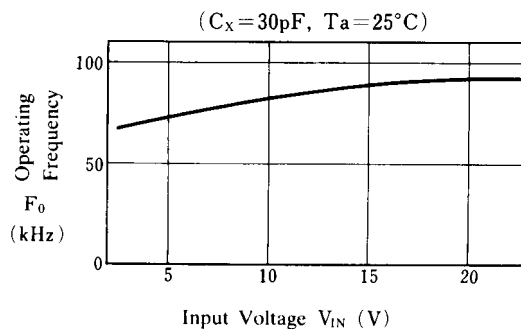
### Operating Current



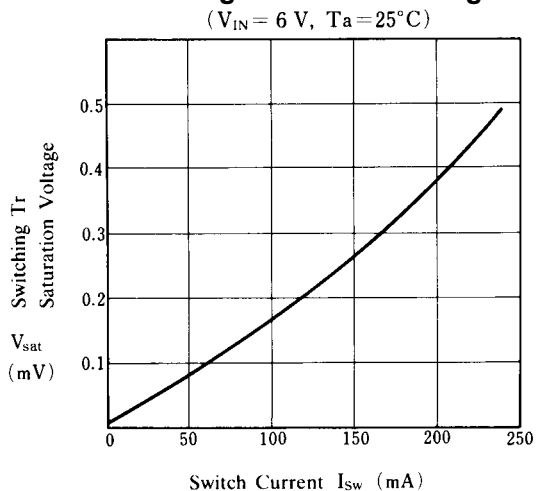
### Operating Frequency



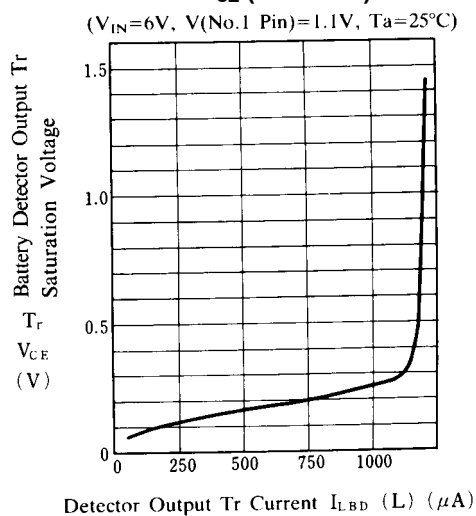
### Operating Frequency



### Switching Tr Saturation Voltage

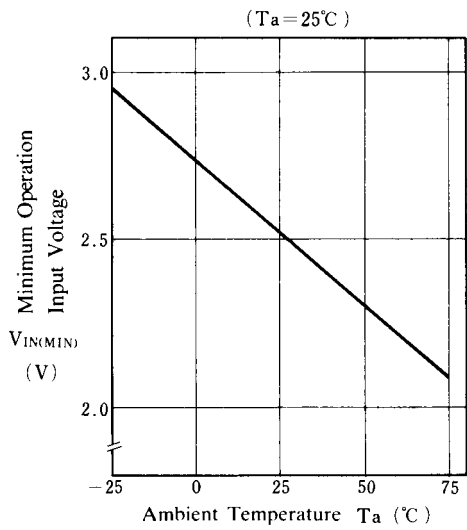


### $V_{CE}$ (No. 8 Pin)

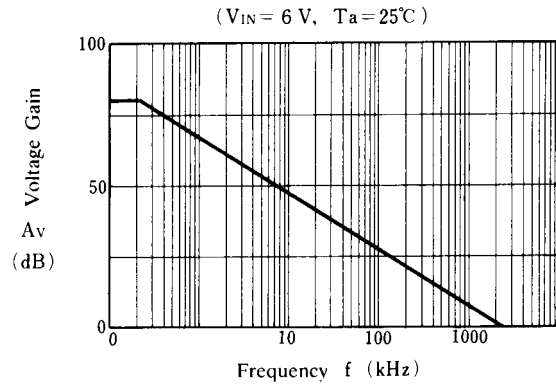


## ■ TYPICAL CHARACTERISTICS

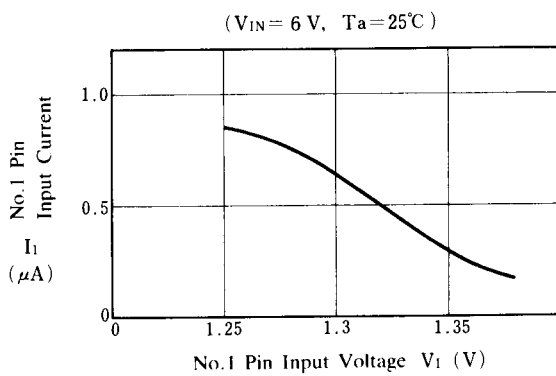
### Minimum Operating Input Voltage



### Voltage Gain



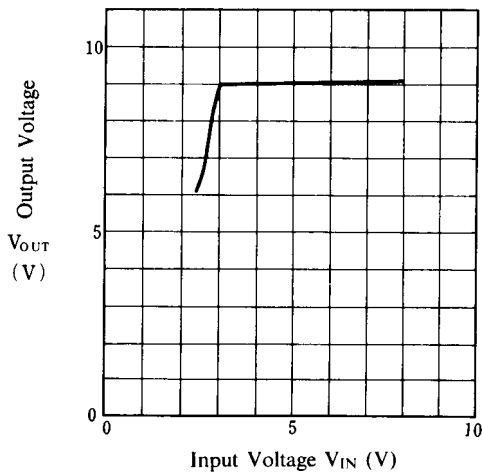
### No.1 Pin Input Current



## ■ TYPICAL CHARACTERISTICS (APPLICATION)

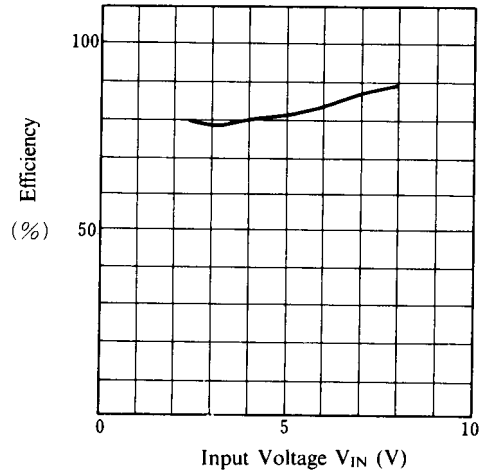
### Output Voltage

( $I_L = 10\text{mA}$ ,  $V_O = 9\text{V}$ ,  $L_X = 470\mu\text{H}$ ,  
 $C_X = 50\text{pF}$ ,  $C_I = 100\mu\text{F}$ ,  $T_a = 25^\circ\text{C}$ )



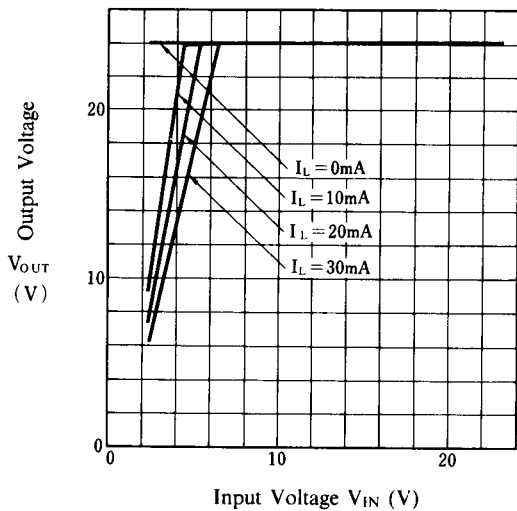
### Efficiency

( $I_L = 10\text{mA}$ ,  $V_O = 9\text{V}$ ,  $L_X = 470\mu\text{H}$ ,  
 $C_X = 50\text{pF}$ ,  $C_I = 100\mu\text{F}$ ,  $T_a = 25^\circ\text{C}$ )



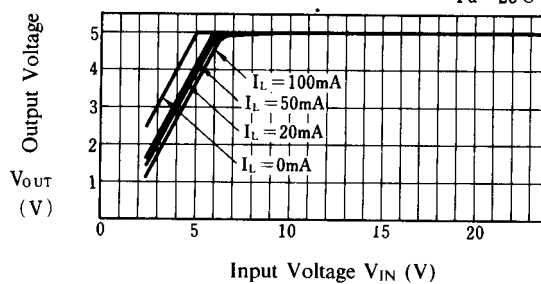
### Output Voltage

( $L_X = 470\mu\text{H}$ ,  $C_X = 20\text{pF}$ ,  $C_I = 100\mu\text{F}$ ,  
 $V_O = 24\text{V}$ ,  $T_a = 25^\circ\text{C}$ )



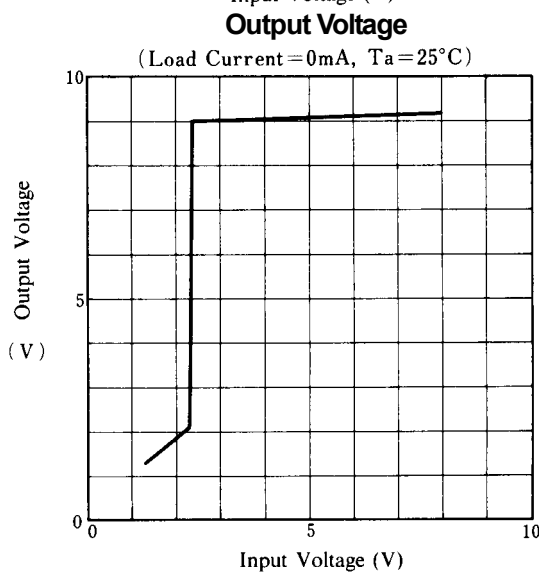
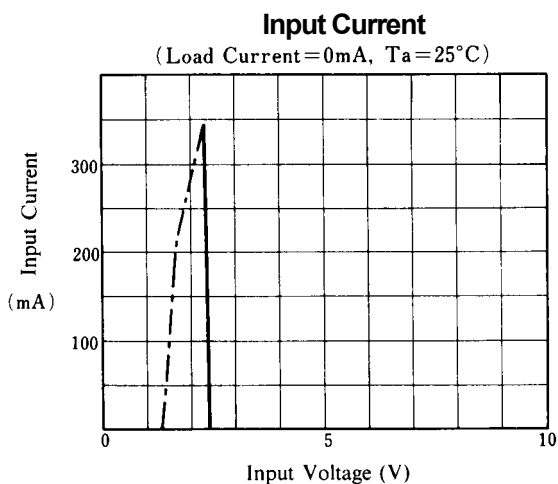
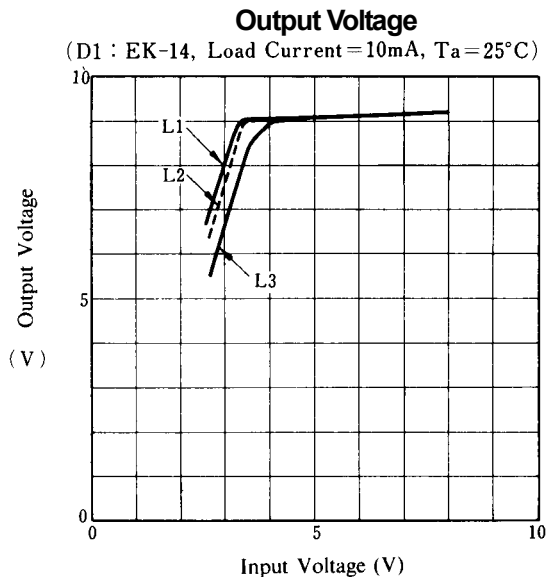
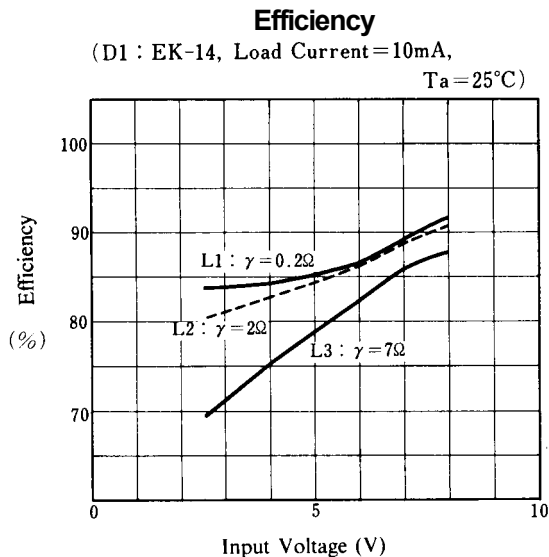
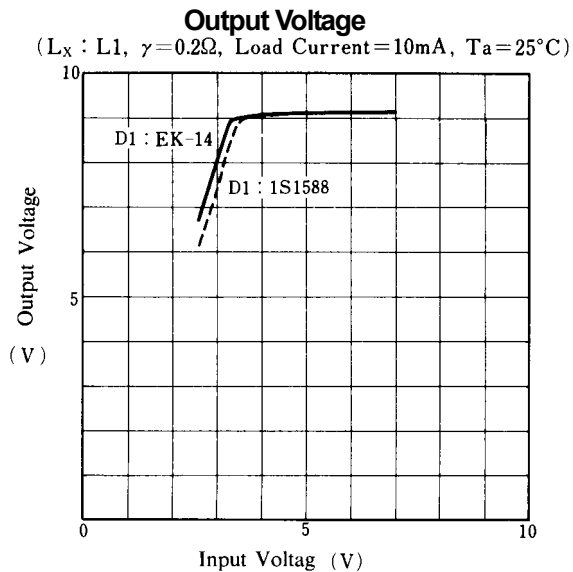
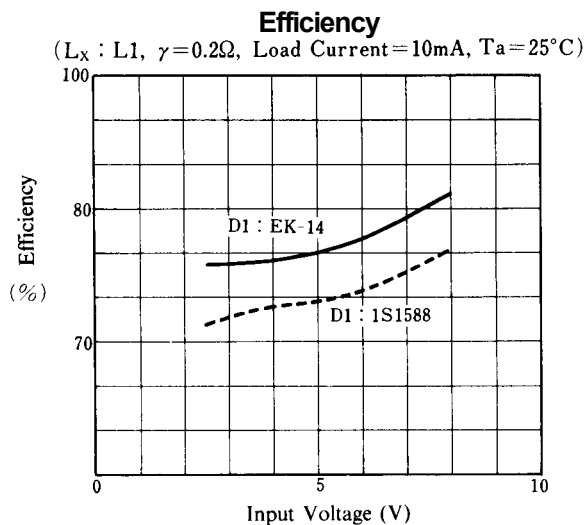
### Output Voltage

( $L_X = 470\mu\text{H}$ ,  $C_X = 50\text{pF}$ ,  $C_I = 100\mu\text{F}$ ,  $V_O = 5\text{V}$ ,  
 $T_a = 25^\circ\text{C}$ )



## ■ TYPICAL CHARACTERISTICS

### (Test Circuits 2)





[CAUTION]

The specifications on this databook are only given for information, without any guarantee as regards either mistakes or omissions. The application circuits in this databook are described only to show representative usages of the product and not intended for the guarantee or permission of any right including the industrial rights.