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Operational Amplifiers

Ground Sense Operational Amplifiers

LM358xxx LM324xxx LM2904xxx LM2902xxx

General Description
LM358xxx and LM2904xxx series are dual ground sense operational amplifiers. LM324xxx and LM2902xxx series are quad. These have features of low current consumption and wide operating voltage range from 3V to 32V (single power supply).

Features
- Operable with a Single Power Supply
- Wide Operating Supply Voltage Range
- Input/output Ground Sense
- High Large Signal Voltage Gain

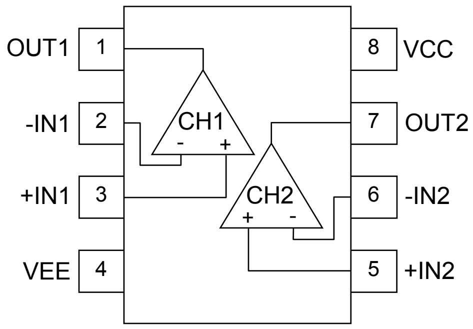
Applications
- Current Sense Application
- Buffer Application Amplifier
- Active Filter
- Consumer Electronics

Key Specifications
- Operating Supply Voltage (Single Supply): 3.0V to 32.0V
- Operating Temperature Range:
  - LM358xxx: -40°C to +85°C
  - LM324xxx: -40°C to +85°C
  - LM2904xxx: -40°C to +125°C
  - LM2902xxx: -40°C to +125°C
- Input Offset Voltage: 4.5mV (Max)
- Input Bias Current: 20nA (Typ)

Packages

Packages	W(Typ) x D(Typ) x H(Max)
SOP8	5.00mm x 6.20mm x 1.71mm
SOP-J8	4.90mm x 6.00mm x 1.65mm
SSOP-B8	3.00mm x 6.40mm x 1.35mm
TSSOP-B8	3.00mm x 6.40mm x 1.20mm
TSSOP-B8J	3.00mm x 4.90mm x 1.10mm
MSOP8	2.90mm x 4.00mm x 0.90mm
SOP14	8.70mm x 6.20mm x 1.71mm
SOP-J14	8.65mm x 6.00mm x 1.65mm
SSOP-B14	5.00mm x 6.40mm x 1.35mm
TSSOP-B14J	5.00mm x 6.40mm x 1.20mm

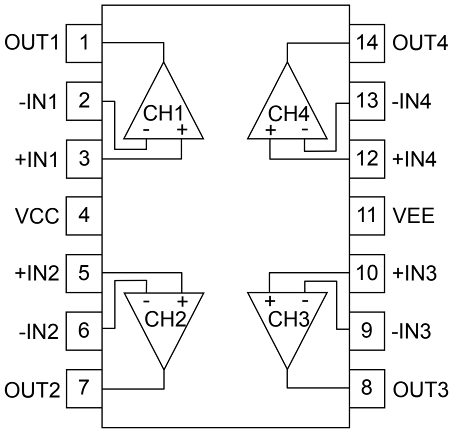
Pin Configuration
LM358F, LM2904F : SOP8
LM358FJ, LM2904FJ : SOP-J8
LM358FV, LM2904FV : SSOP-B8
LM358FVT, LM2904FVT : TSSOP-B8
LM358FVJ, LM2904FVJ : TSSOP-B8J
LM358FVM, LM2904FVM : MSOP8



Pin No.	Pin Name
1	OUT1
2	-IN1
3	+IN1
4	VEE
5	+IN2
6	-IN2
7	OUT2
8	VCC

○Product structure : Silicon monolithic integrated circuit ○This product has no designed protection against radioactive rays.

LM324F, LM2902F : SOP14
LM324FJ, LM2902FJ : SOP-J14
LM324FV, LM2902FV : SSOP-B14
LM324FVJ, LM2902FVJ : TSSOP-B14J



Pin No.	Pin Name
1	OUT1
2	-IN1
3	+IN1
4	VCC
5	+IN2
6	-IN2
7	OUT2
8	OUT3
9	-IN3
10	+IN3
11	VEE
12	+IN4
13	-IN4
14	OUT4

Absolute Maximum Ratings (T_A=25°C)

Parameter	Symbol		Rating				Unit
			LM358xxx	LM324xxx	LM2904xxx	LM2902xxx	
Supply Voltage	V_{CC}-V_{EE}		36				V
Power Dissipation	P_D	SOP8	0.68 (Note 1,9)	-	0.68 (Note 1,9)	-	W
		SOP-J8	0.67 (Note 2,9)	-	0.67 (Note 2,9)	-	
		SSOP-B8	0.62 (Note 3,9)	-	0.62 (Note 3,9)	-	
		TSSOP-B8	0.62 (Note 3,9)	-	0.62 (Note 3,9)	-	
		TSSOP-B8J	0.58 (Note 4,9)	-	0.58 (Note 4,9)	-	
		MSOP8	0.58 (Note 4,9)	-	0.58 (Note 4,9)	-	
		SOP14	-	0.56 (Note 5,9)	-	0.56 (Note 5,9)	
		SOP-J14	-	1.02 (Note 6,9)	-	1.02 (Note 6,9)	
		SSOP-B14	-	0.87 (Note 7,9)	-	0.87 (Note 7,9)	
		TSSOP-B14J	-	0.85 (Note 8,9)	-	0.85 (Note 8,9)	
Differential Input Voltage (Note 10)	V_{ID}		36				V
Input Common-mode Voltage Range	V_{ICM}		(V_{EE}-0.3) to (V_{EE}+36)				V
Input Current (Note 11)	I_I		±10				mA
Operating Supply Voltage	V_{opr}		3.0 to 32.0				V
Operating Temperature Range	T_{opr}		-40 to +85		-40 to +125		°C
Storage Temperature Range	T_{stg}		-55 to +150				°C
Maximum Junction Temperature	T_{jmax}		150				°C

(Note 1) Reduce by 5.5mW per 1°C above 25°C.
(Note 2) Reduce by 5.4mW per 1°C above 25°C.
(Note 3) Reduce by 5.0mW per 1°C above 25°C.
(Note 4) Reduce by 4.7mW per 1°C above 25°C.
(Note 5) Reduce by 4.5mW per 1°C above 25°C.
(Note 6) Reduce by 8.2mW per 1°C above 25°C.
(Note 7) Reduce by 7.0mW per 1°C above 25°C.
(Note 8) Reduce by 6.8mW per 1°C above 25°C.
(Note 9) Mounted on an FR4 glass epoxy PCB 70mm×70mm×1.6mm (Copper foil area less than 3%).
(Note 10) Differential Input Voltage is the voltage difference between the inverting and non-inverting inputs.
The input pin voltage is set to more than V_{EE}.
(Note 11) An excessive input current will flow when input voltages of less than V_{EE}-0.6V are applied.
The input current can be set to less than the rated current by adding a limiting resistor.

Caution: Operating the IC over the absolute maximum ratings may damage the IC. The damage can either be a short circuit between pins or an open circuit between pins and the internal circuitry. Therefore, it is important to consider circuit protection measures, such as adding a fuse, in case the IC is operated over the absolute maximum ratings.

Electrical Characteristics

○LM358xxx, LM2904xxx (Unless otherwise specified V_{CC}=+5V, V_{EE}=0V)

Parameter	Symbol	Temperature Range	Limits Min	Limits Typ	Limits Max	Unit	Condition
Input Offset Voltage(Note 12,13)	V_{IO}	25°C	-	1	4.5	mV	V_{OUT}=1.4V
		Full Range	-	-	5		V_{CC}=5 to 30V, V_{OUT}=1.4V
Input Offset Voltage Drift(Note 12)	$\Delta V_{IO}/\Delta T$	-	-	6	-	μV/°C	V_{OUT}=1.4V
Input Offset Current(Note 12,13)	I_{IO}	25°C	-	2	50	nA	V_{OUT}=1.4V
		Full Range	-	-	200		
Input Bias Current(Note 12,13)	I_B	25°C	-	20	250	nA	V_{OUT}=1.4V
		Full Range	-	-	300		
Supply Current(Note 13)	I_{CC}	25°C	-	0.6	1.2	mA	R_L=∞, All Op-Amps
		Full Range	-	-	1.5		
Maximum Output Voltage (High)(Note 13)	V_{OH}	25°C	3.5	-	-	V	R_L=2kΩ
		Full Range	27	28	-		V_{CC}=30V, R_L=10kΩ
Maximum Output Voltage (Low)(Note 13)	V_{OL}	Full Range	-	5	20	mV	R_L=∞
Large Signal Voltage Gain	A_V	25°C	25	100	-	V/mV	R_L≧2kΩ, V_{CC}=15V V_{OUT}=1.4 to 11.4V
			88	100	-	dB	
Input Common-mode Voltage Range	V_{ICM}	25°C	0	-	3.5	V	V_{ICM}=V_{EE} to (V_{CC}-1.5V) V_{OUT}=1.4V
Input Common-mode Voltage Range (VEE side) (Note 14)	V_{ICM}	Full Range	-	0.1	-	V	V_{OUT}=1.4V
Common-mode Rejection Ratio	CMRR	25°C	70	80	-	dB	V_{OUT}=1.4V
Power Supply Rejection Ratio	PSRR	25°C	65	100	-	dB	V_{CC}=5 to 30V
Output Source Current(Note 13,15)	I_{SOURCE}	25°C	20	30	-	mA	V_{+IN}=1V, V_{-IN}=0V V_{OUT}=0V, Short Current
		Full Range	10	-	-		
Output Sink Current(Note 13,15)	I_{SINK}	25°C	20	27	-	mA	V_{+IN}=0V, V_{-IN}=1V V_{OUT}=5V, Short Current
		Full Range	5	-	-		
		25°C	20	50	-	μA	V_{+IN}=0V, V_{-IN}=1V V_{OUT}=200mV
Channel Separation	CS	25°C	-	120	-	dB	f=1kHz, Input Referred
Slew Rate	SR	25°C	-	0.3	-	V/μs	V_{CC}=15V, Av=0dB R_L=2kΩ, C_L=100pF
Gain Bandwidth	GBW	25°C	-	0.8	-	MHz	V_{CC}=15V, V_{EE}=-15V R_L=2kΩ, C_L=100pF
Phase Margin	θ	25°C	-	80	-	deg	Av=40dB
Input Referred Noise Voltage	V_N	25°C	-	40	-	$nV/\sqrt{Hz}$	V_{CC}=15V, V_{EE}=-15V R_S=100Ω, V_{IN}=0V, f=1kHz

(Note 12) Absolute value
(Note 13) LM358xxx Full Range: T_A=-40°C to +85°C, LM2904xxx Full Range: T_A=-40°C to +125°C
(Note 14) LM2904xxx only.
(Note 15) Consider the power dissipation of the IC under high temperature when selecting the output current value.
There may be a case where the output current value is reduced due to the rise in IC temperature caused by the heat generated inside the IC.

Electrical Characteristics - continued

○LM324xxx, LM2902xxx (Unless otherwise specified V_{CC}=+5V, V_{EE}=0V)

Parameter	Symbol	Temperature Range	Limits Min	Limits Typ	Limits Max	Unit	Condition
Input Offset Voltage(Note 16,17)	V_{IO}	25°C	-	1	4.5	mV	V_{OUT}=1.4V
		Full Range	-	-	5		V_{CC}=5 to 30V, V_{OUT}=1.4V
Input Offset Voltage Drift(Note 17)	$\Delta V_{IO}/\Delta T$	-	-	6	-	μV/°C	V_{OUT}=1.4V
Input Offset Current(Note 16,17)	I_{IO}	25°C	-	2	50	nA	V_{OUT}=1.4V
		Full Range	-	-	200		
Input Bias Current(Note 16,17)	I_B	25°C	-	20	250	nA	V_{OUT}=1.4V
		Full Range	-	-	300		
Supply Current(Note 17)	I_{CC}	25°C	-	1	2	mA	R_L=∞, All Op-Amps
		Full Range	-	-	2.5		
Maximum Output Voltage (High)(Note 17)	V_{OH}	25°C	3.5	-	-	V	R_L=2kΩ
		Full Range	27	28	-		V_{CC}=30V, R_L=10kΩ
Maximum Output Voltage (Low)(Note 17)	V_{OL}	Full Range	-	5	20	mV	R_L=∞
Large Signal Voltage Gain	A_V	25°C	25	100	-	V/mV	R_L≧2kΩ, V_{CC}=15V V_{OUT}=1.4 to 11.4V
			88	100	-	dB	
Input Common-mode Voltage Range	V_{ICM}	25°C	0	-	3.5	V	V_{ICM}=V_{EE} to (V_{CC}-1.5V) V_{OUT}=1.4V
Input Common-mode Voltage Range (VEE side) (Note 18)	V_{ICM}	Full Range	-	0.1	-	V	V_{OUT}=1.4V
Common-mode Rejection Ratio	CMRR	25°C	70	80	-	dB	V_{OUT}=1.4V
Power Supply Rejection Ratio	PSRR	25°C	65	100	-	dB	V_{CC}=5 to 30V
Output Source Current(Note 17,19)	I_{SOURCE}	25°C	20	30	-	mA	V_{+IN}=1V, V_{-IN}=0V V_{OUT}=0V, Short Current
		Full Range	10	-	-		
Output Sink Current(Note 17,19)	I_{SINK}	25°C	20	27	-	mA	V_{+IN}=0V, V_{-IN}=1V V_{OUT}=5V, Short Current
		Full Range	5	-	-		
		25°C	20	50	-	μA	V_{+IN}=0V, V_{-IN}=1V V_{OUT}=200mV
Channel Separation	CS	25°C	-	120	-	dB	f=1kHz, Input Referred
Slew Rate	SR	25°C	-	0.3	-	V/μs	V_{CC}=15V, Av=0dB R_L=2kΩ, C_L=100pF
Gain Bandwidth	GBW	25°C	-	0.8	-	MHz	V_{CC}=15V, V_{EE}=-15V R_L=2kΩ, C_L=100pF
Phase Margin	θ	25°C	-	80	-	deg	Av=40dB
Input Referred Noise Voltage	V_N	25°C	-	40	-	$nV/\sqrt{Hz}$	V_{CC}=15V, V_{EE}=-15V R_S=100Ω, V_{IN}=0V, f=1kHz

(Note 16) Absolute value
(Note 17) LM324xxx Full Range: T_A=-40°C to +85°C, LM2902xxx Full Range: T_A=-40°C to +125°C
(Note 18) LM2902xxx only.
(Note 19) Consider the power dissipation of the IC under high temperature when selecting the output current value.
There may be a case where the output current value is reduced due to the rise in IC temperature caused by the heat generated inside the IC.

Description of Electrical Characteristics

Below are the descriptions of the relevant electrical terms used in this datasheet. Items and symbols used are also shown. Note that item names, symbols, and their meanings may differ from those of another manufacturer's document or general document.

1. Absolute Maximum Ratings

Absolute maximum rating items indicate the conditions which must not be exceeded. Application of voltage in excess of the absolute maximum rating or use out of absolute maximum rated temperature environment may cause deterioration of electrical characteristics.

(1) Supply Voltage (V_{CC}/V_{EE})
Indicates the maximum voltage that can be applied between the VCC pin and VEE pin without deterioration of characteristics of internal circuit.

(2) Differential Input Voltage (V_{ID})
Indicates the maximum voltage that can be applied between the non-inverting and inverting pins without damaging the IC.

(3) Input Common-mode Voltage Range (V_{ICM})
Indicates the maximum voltage that can be applied to the non-inverting and inverting pins without deterioration or destruction of electrical characteristics. Input common-mode voltage range of the maximum ratings does not assure normal operation of IC. For normal operation, use the IC within the input common-mode voltage range characteristics.

(4) Power Dissipation (P_D)
Indicates the power that can be consumed by the IC when mounted on a specific board at the ambient temperature 25°C (normal temperature). As for package product, P_D is determined by the temperature that can be permitted by the IC in the package (maximum junction temperature) and the thermal resistance of the package.

2. Electrical Characteristics

(1) Input Offset Voltage (V_{IO})
Indicates the voltage difference between non-inverting pin and inverting pin. It can be translated to the input voltage difference required for setting the output voltage to 0V.

(2) Input Offset Voltage Drift ($\Delta V_{IO}/\Delta T$)
Denotes the ratio of the input offset voltage fluctuation to the ambient temperature fluctuation.

(3) Input Offset Current (I_{IO})
Indicates the difference of input bias current between the non-inverting and inverting pins.

(4) Input Bias Current (I_B)
Indicates the current that flows into or out of the input pin. It is defined by the average of input bias currents at the non-inverting and inverting pins.

(5) Supply Current (I_{CC})
Indicates the current that flows within the IC under specified no-load conditions.

(6) Maximum Output Voltage (High) / Maximum Output Voltage (Low) (V_{OH}/V_{OL})
Indicates the voltage range of the output under specified load condition. It is typically divided into maximum output voltage high and low. Maximum output voltage high indicates the upper limit of output voltage. Maximum output voltage low indicates the lower limit.

(7) Large Signal Voltage Gain (A_V)
Indicates the amplification rate (gain) of output voltage against the voltage difference between non-inverting pin and inverting pin. It is normally the amplification rate (gain) with reference to DC voltage.
Av = (Output Voltage) / (Differential Input Voltage)

(8) Input Common-mode Voltage Range (V_{ICM})
Indicates the input voltage range at which IC normally operates.

(9) Common-mode Rejection Ratio (CMRR)
Indicates the ratio of fluctuation of input offset voltage when the input common-mode voltage is changed. It is normally the fluctuation of DC.
CMRR = (Change of Input Common-mode Voltage)/(Input Offset Fluctuation)

(10) Power Supply Rejection Ratio (PSRR)
Indicates the ratio of fluctuation of input offset voltage when supply voltage is changed.
It is normally the fluctuation of DC.
PSRR= (Change of Power Supply Voltage)/(Input Offset Fluctuation)

(11) Output Source Current/ Output Sink Current (I_{SOURCE} / I_{SINK})
The maximum current that the IC can output under specific output conditions. The output source current indicates the current flowing out from the IC, and the output sink current indicates the current flowing into the IC.

(12) Channel Separation (CS)
Indicates the fluctuation in the output voltage of the driven channel with reference to the change of output voltage of the channel which is not driven.

(13) Slew Rate (SR)
Indicates the rate of the change of the output voltage with time when a step input signal is applied.

(14) Gain Bandwidth (GBW)
The product of the open-loop voltage gain and the frequency at which the voltage gain decreases 6dB/octave.

(15) Phase Margin (θ)
Indicates the margin of phase from 180 degree phase lag at unity gain frequency.

(16) Input Referred Noise Voltage (V_N)
Indicates a noise voltage generated inside the operational amplifier equivalent by ideal voltage source connected in series with input pin.

Typical Performance Curves

○LM358xxx, LM2904xxx

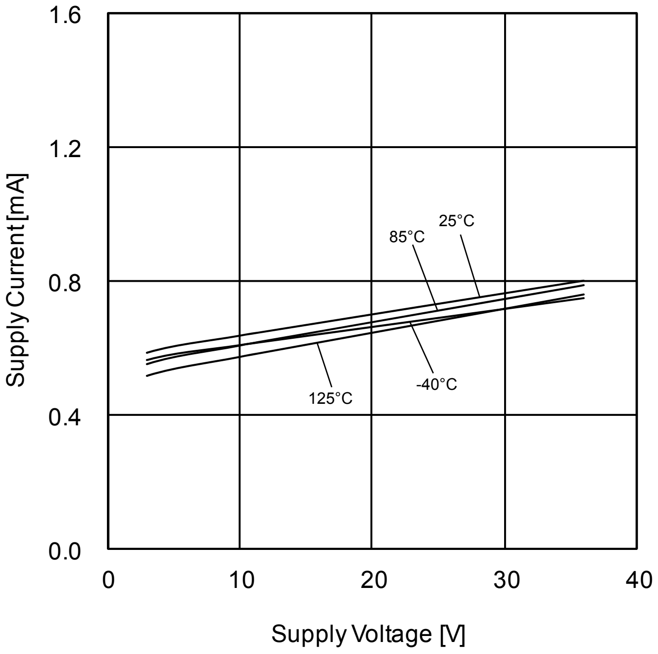


Figure 1. Supply Current vs Supply Voltage

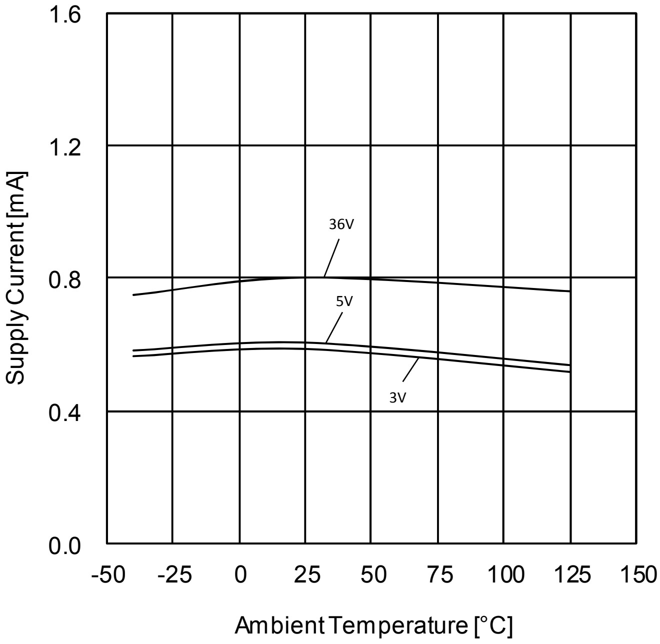


Figure 2. Supply Current vs Ambient Temperature

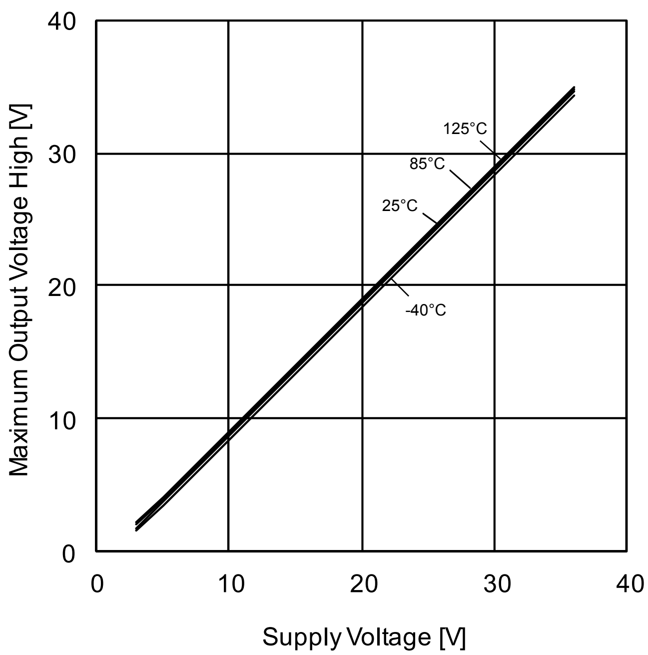


Figure 3. Maximum Output Voltage (High) vs Supply Voltage (R_L=10kΩ)

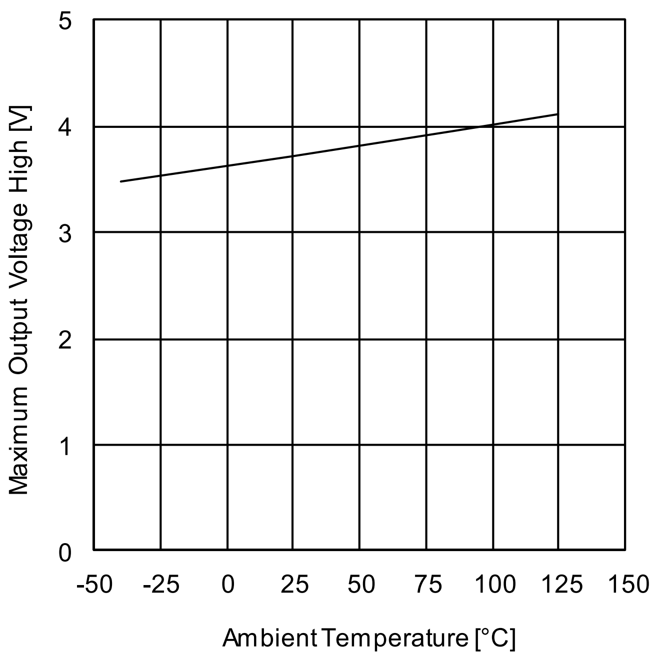


Figure 4. Maximum Output Voltage (High) vs Ambient Temperature (V_{CC}=5V, R_L=10kΩ)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○**LM358xxx, LM2904xxx**

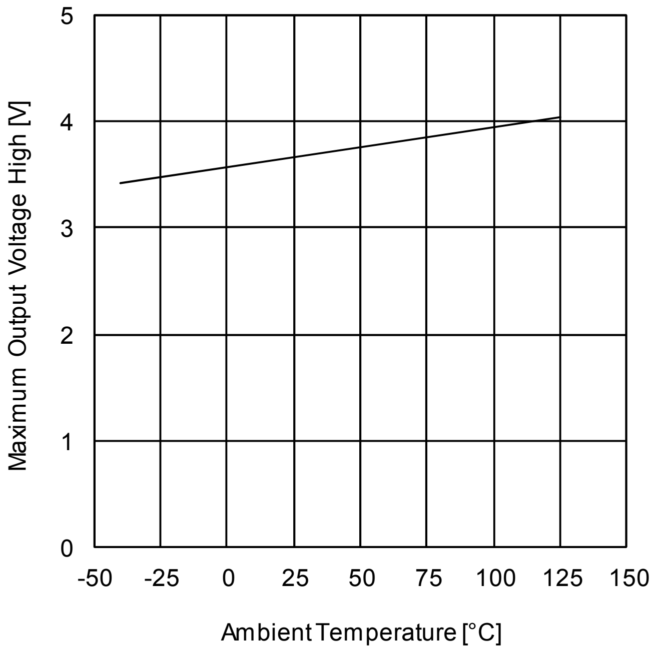


Figure 5. Maximum Output Voltage (High) vs Ambient Temperature (V_{CC}=5V, R_L=2kΩ)

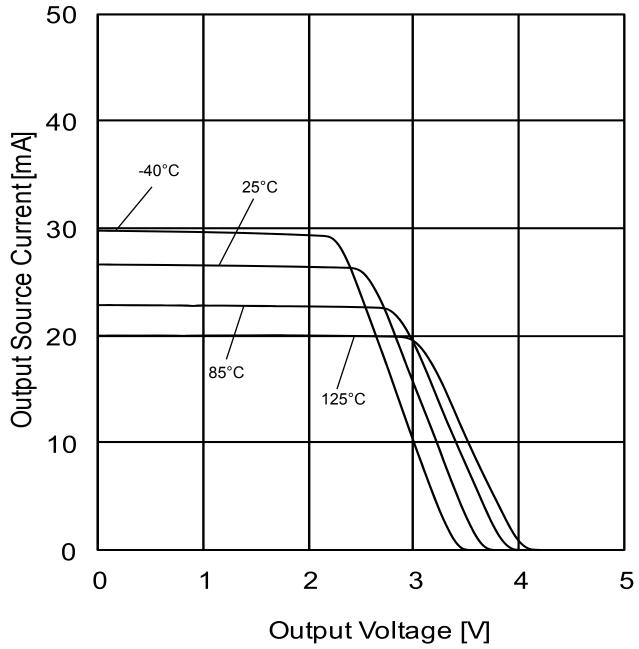


Figure 6. Output Source Current vs Output Voltage (V_{CC}=5V)

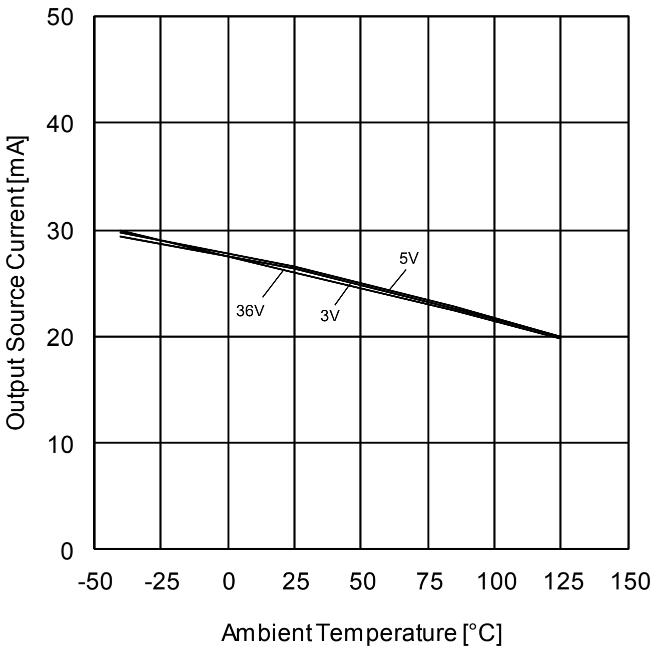


Figure 7. Output Source Current vs Ambient Temperature (V_{OUT}=0V)

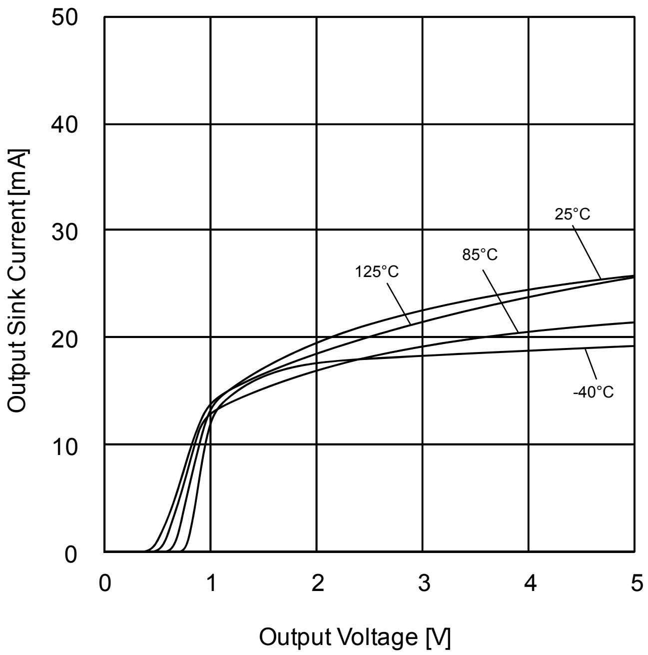


Figure 8. Output Sink Current vs Output Voltage (V_{CC}=5V)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM358xxx, LM2904xxx

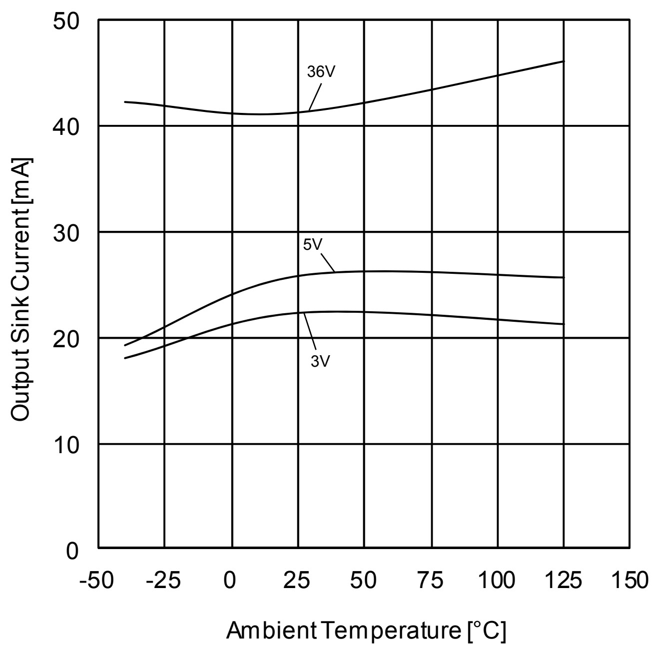


Figure 9. Output Sink Current vs Ambient Temperature (V_{OUT}=V_{CC})

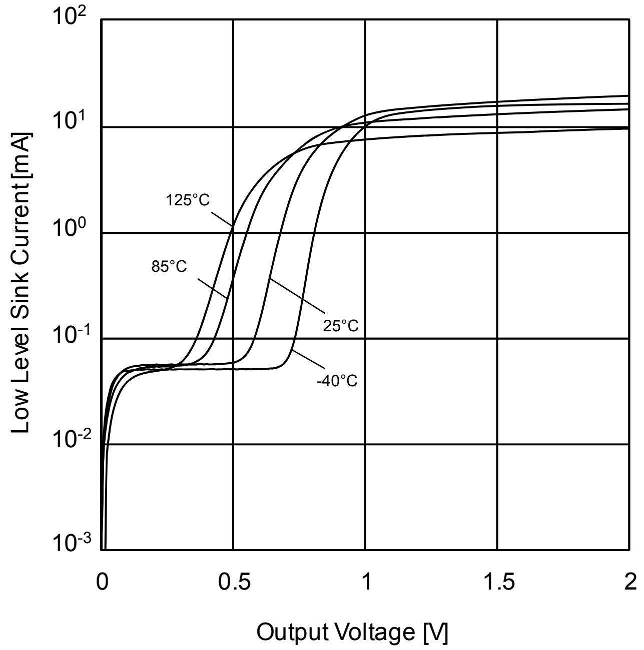


Figure 10. Low Level Sink Current vs Output Voltage (V_{CC}=5V)

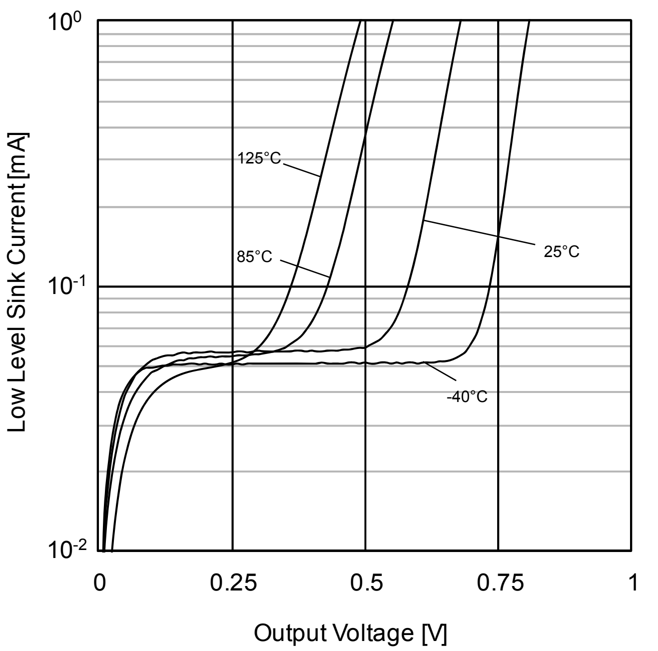


Figure 11. Low Level Sink Current vs Output Voltage (Enlarged view) (V_{CC}=5V)

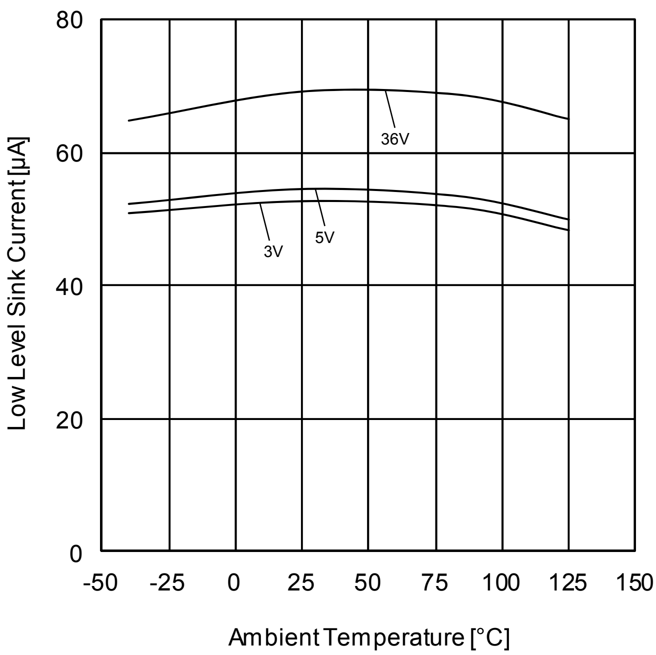


Figure 12. Low Level Sink Current vs Ambient Temperature (V_{OUT}=200mV)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM358xxx, LM2904xxx

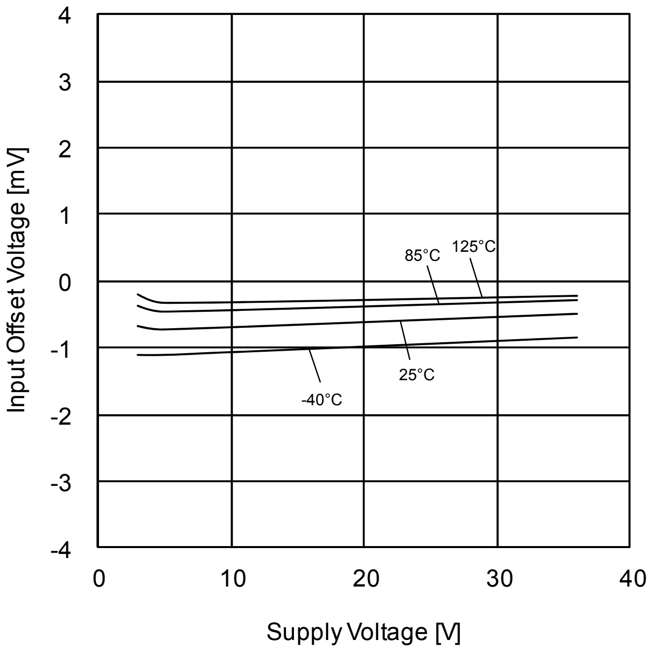


Figure 13. Input Offset Voltage vs Supply Voltage (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

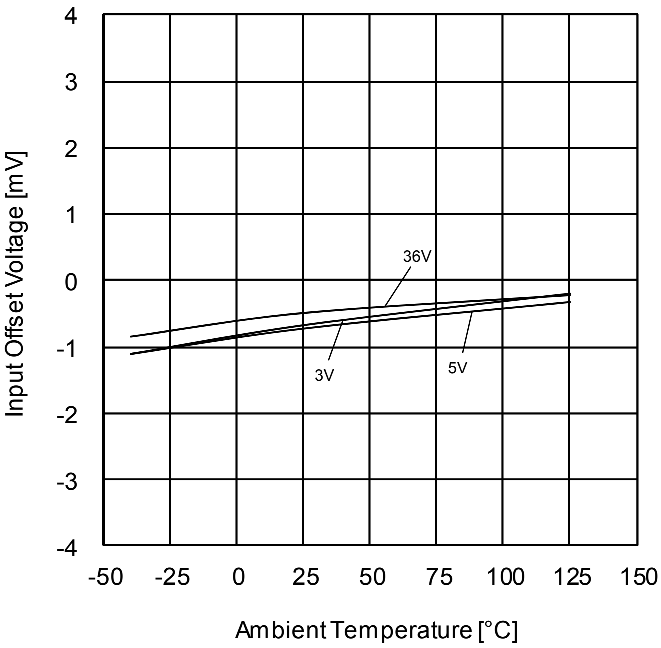


Figure 14. Input Offset Voltage vs Ambient Temperature (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

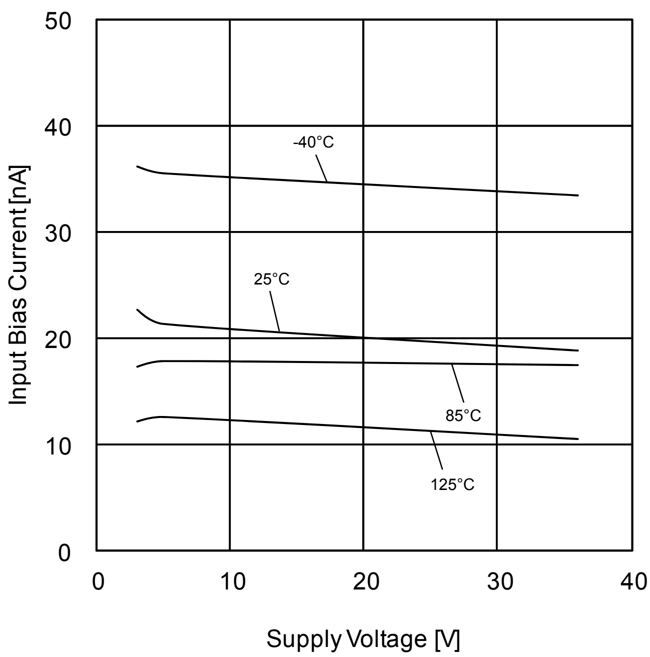


Figure 15. Input Bias Current vs Supply Voltage (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

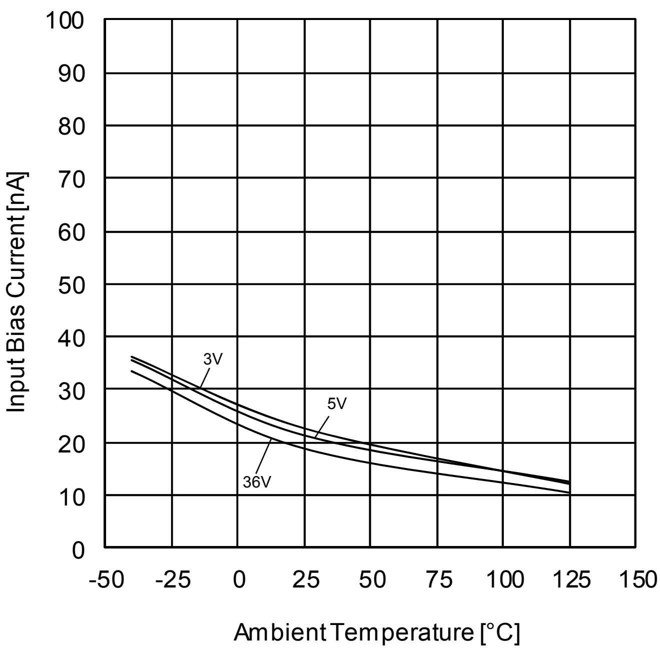


Figure 16. Input Bias Current vs Ambient Temperature (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM358xxx, LM2904xxx

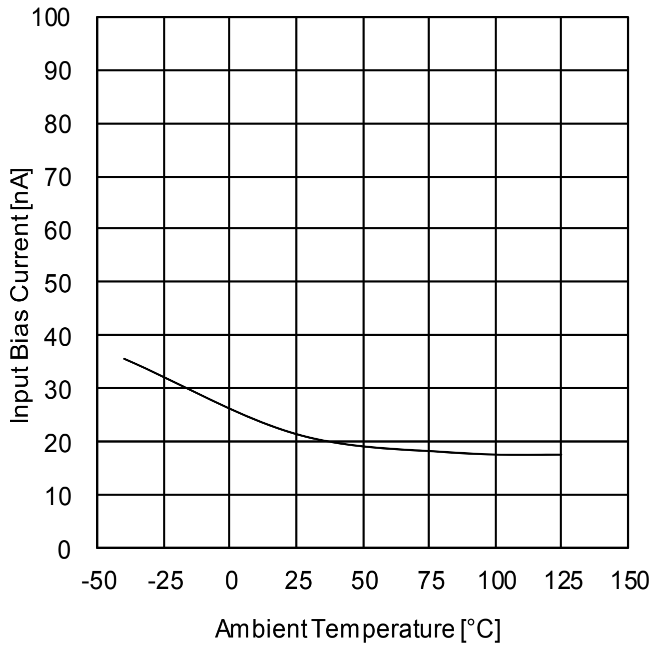


Figure 17. Input Bias Current vs Ambient Temperature (V_{CC}=30V, V_{ICM}=28V, E_K=-1.4V)

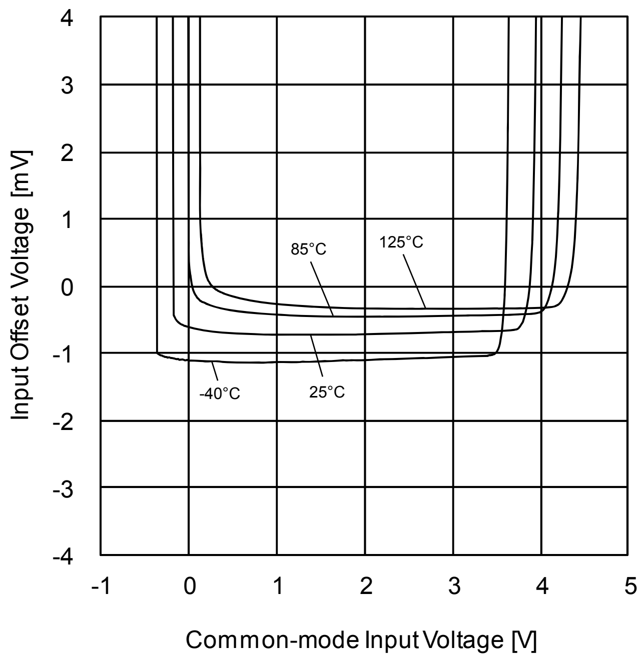


Figure 18. Input Offset Voltage vs Common-mode Input Voltage (V_{CC}=5V)

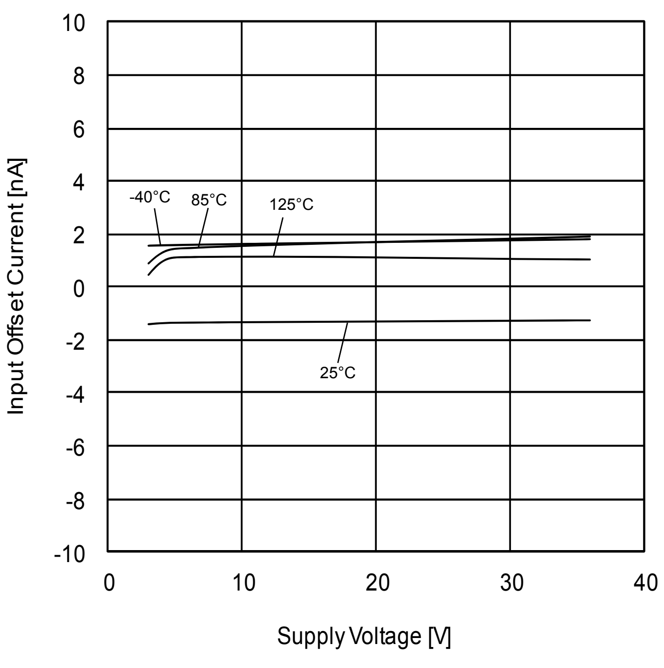


Figure 19. Input Offset Current vs Supply Voltage (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

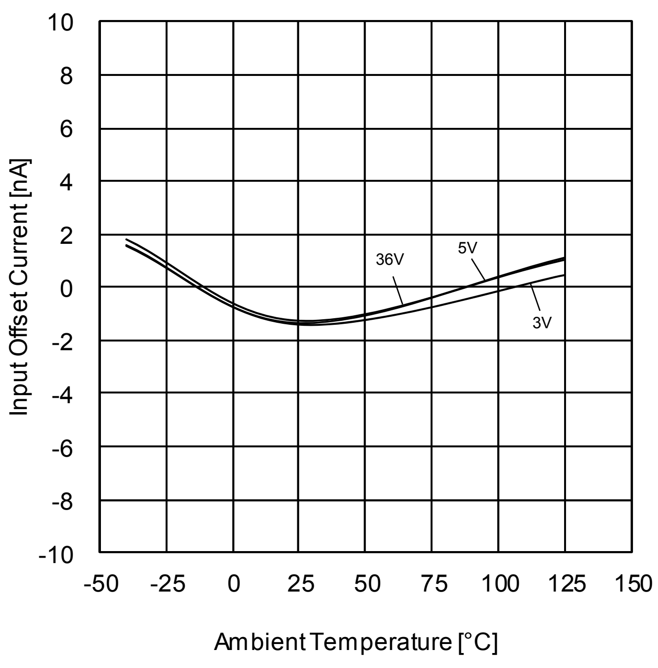


Figure 20. Input Offset Current vs Ambient Temperature (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM358xxx, LM2904xxx

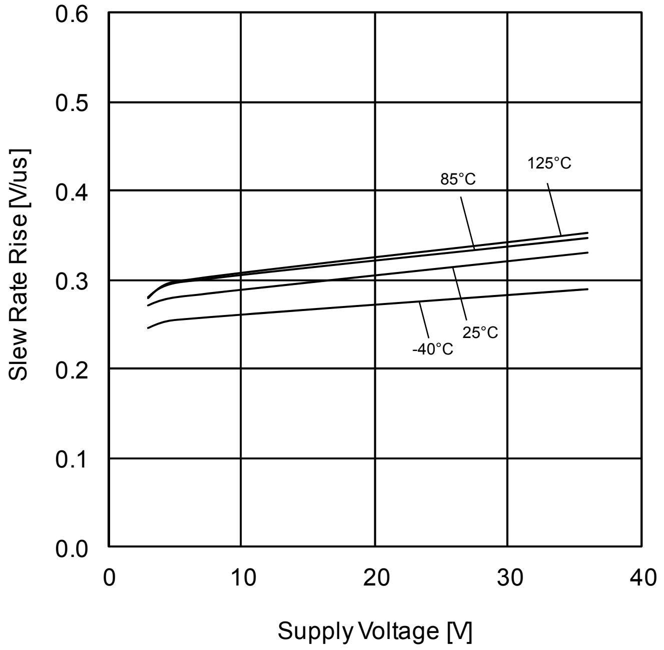


Figure 21. Slew Rate Rise vs Supply Voltage
(R_L=2kΩ, Low to High)

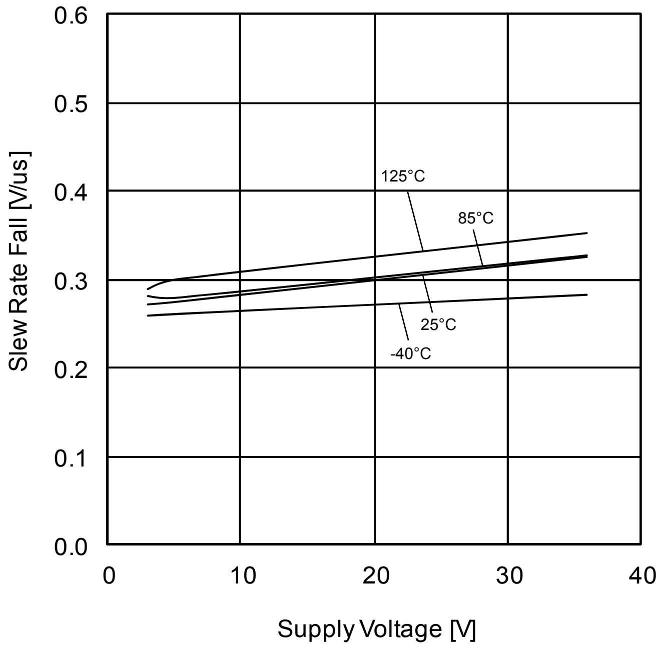


Figure 22. Slew Rate Fall vs Supply Voltage
(R_L=2kΩ, High to Low)

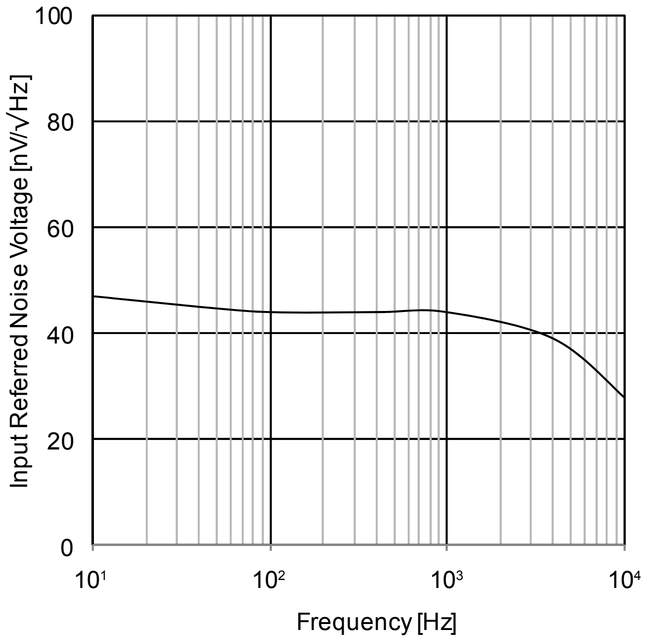


Figure 23. Input Referred Noise Voltage vs
Frequency (V_{CC}=5V)

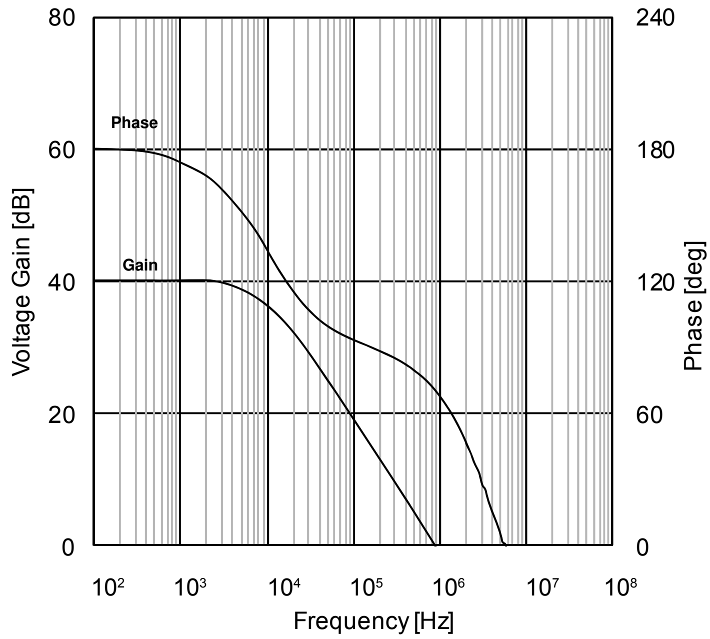


Figure 24. Voltage Gain, Phase vs Frequency
(V_{CC}=30V, R_L=2kΩ, C_L=100pF)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○**LM358xxx, LM2904xxx**

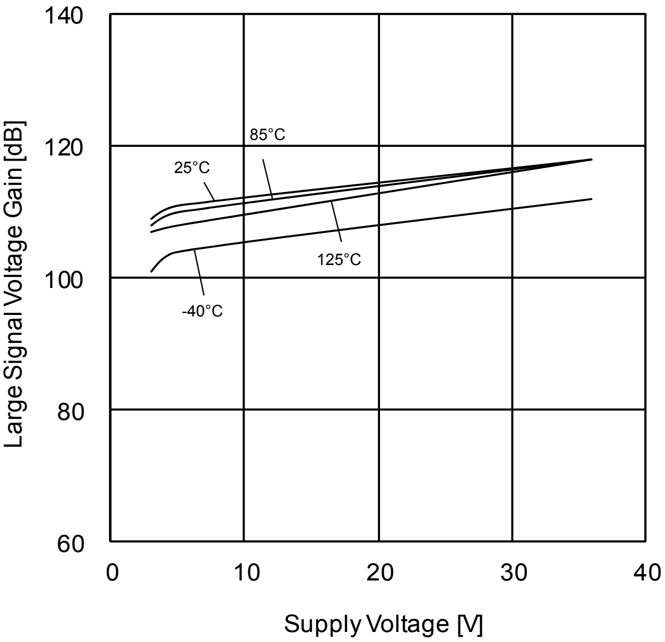


Figure 25. Large Signal Voltage Gain vs Supply Voltage (R_L=2kΩ)

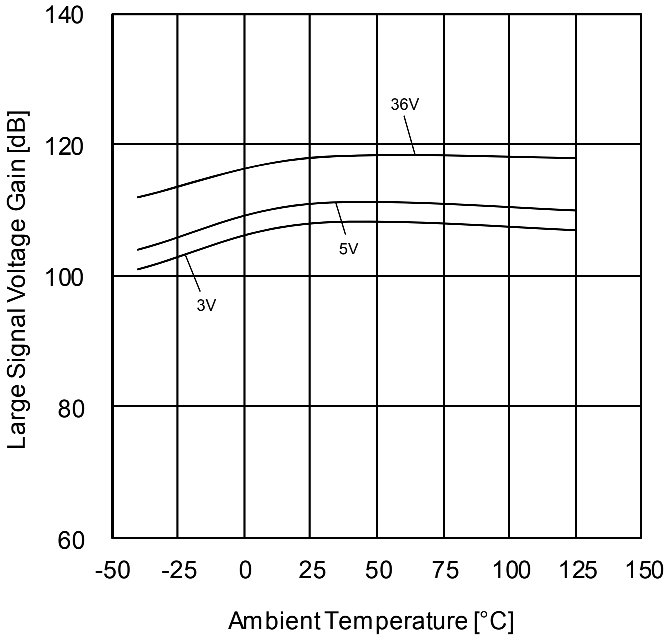


Figure 26. Large Signal Voltage Gain vs Ambient Temperature (R_L=2kΩ)

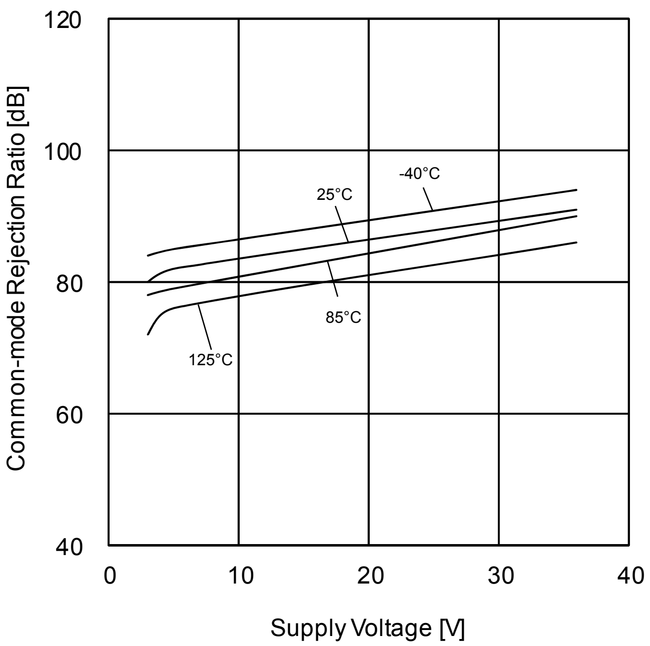


Figure 27. Common-mode Rejection Ratio vs Supply Voltage

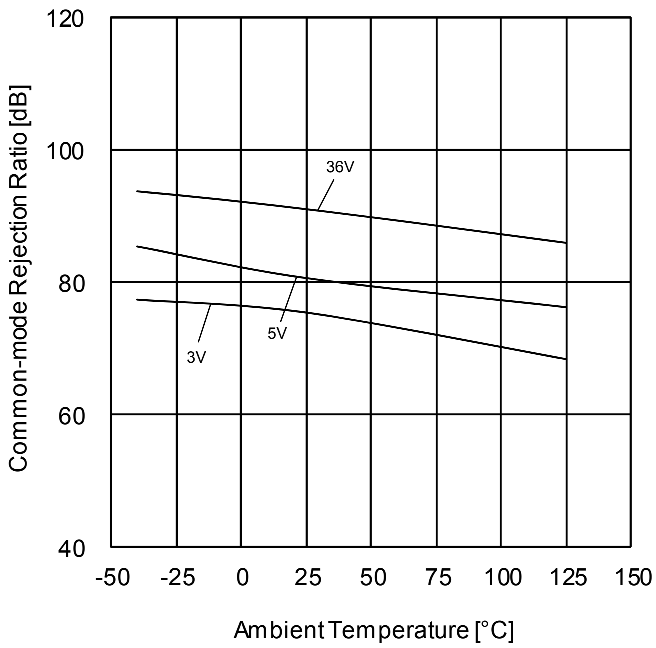


Figure 28. Common-mode Rejection Ratio vs Ambient Temperature

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM358xxx, LM2904xxx

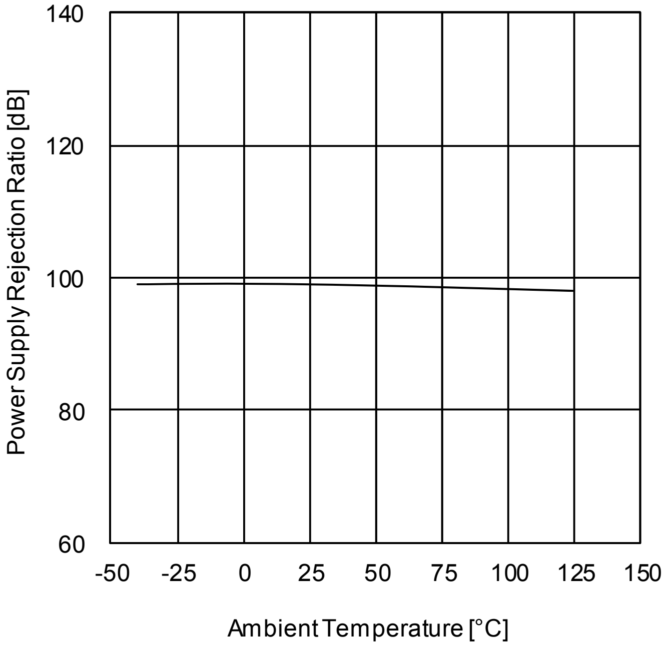


Figure 29. Power Supply Rejection Ratio vs Ambient Temperature

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM358xxx: -40°C to +85°C LM2904xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM324xxx, LM2902xxx

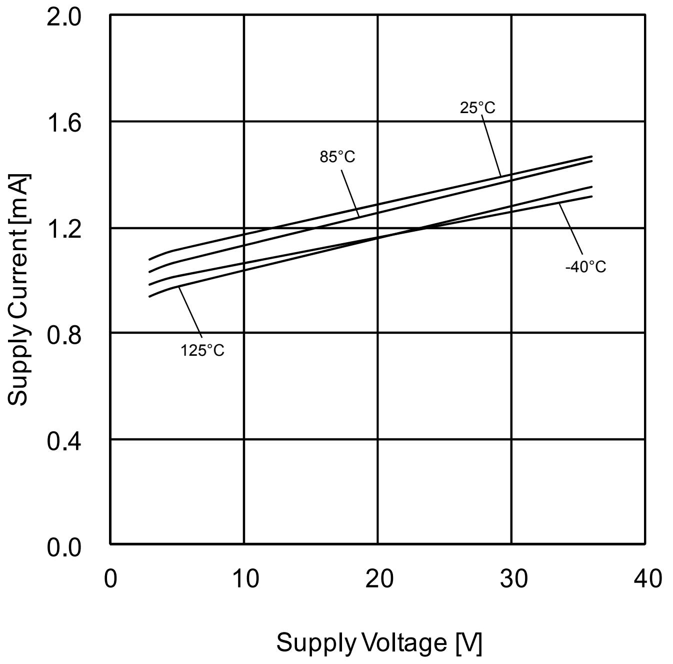


Figure 30. 回路電流ー電源電圧特性

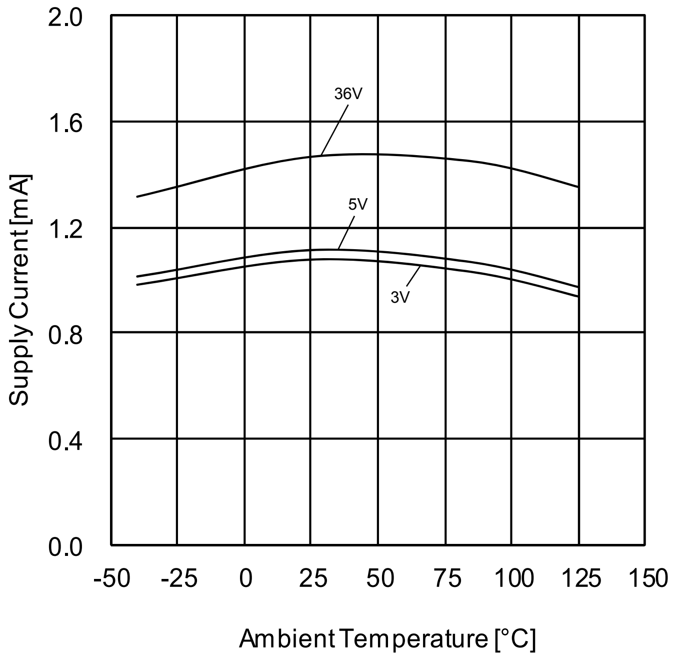


Figure 31. Supply Current vs Ambient Temperature

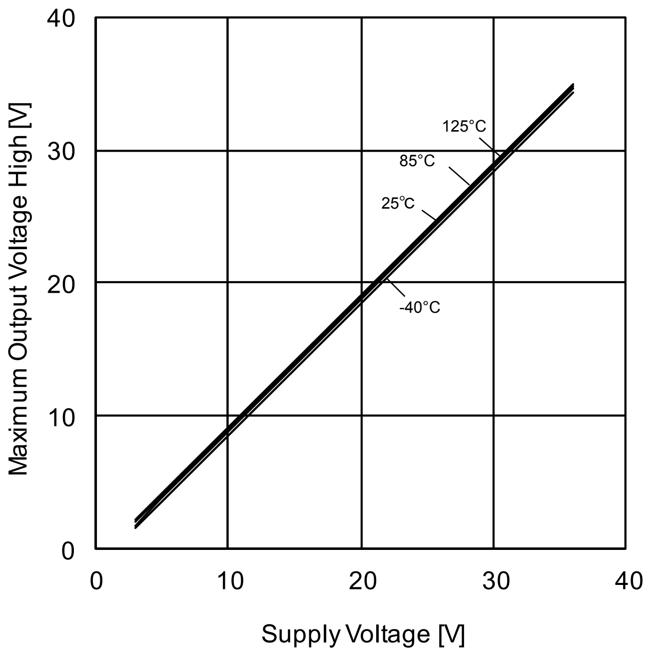


Figure 32. Maximum Output Voltage (High) vs Supply Voltage (R_L=10kΩ)

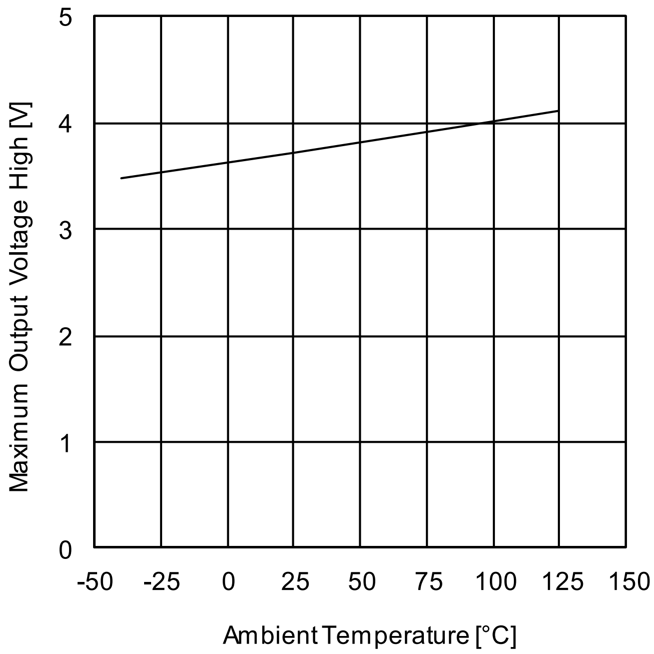


Figure 33. Maximum Output Voltage (High) vs Ambient Temperature (V_{CC}=5V, R_L=10kΩ)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Typical Performance Curves - continued

○**LM324xxx, LM2902xxx**

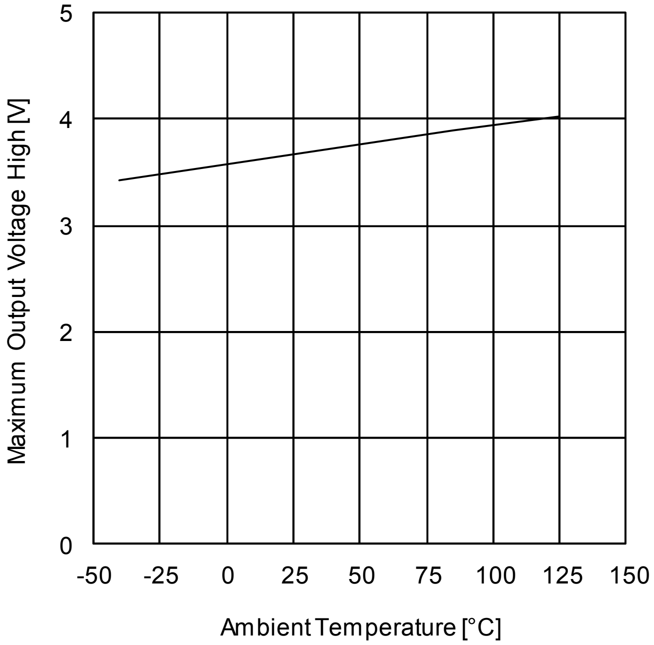


Figure 34. Maximum Output Voltage (High) vs Ambient Temperature (V_{CC}=5V, R_L=2kΩ)

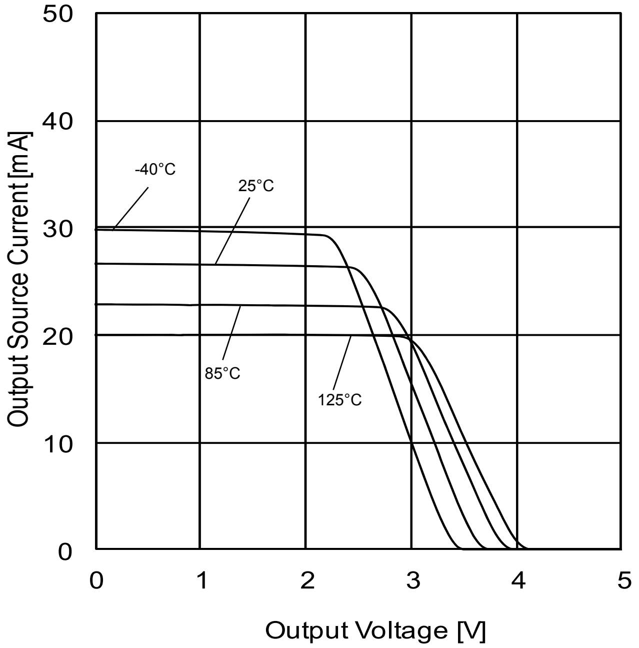


Figure 35. Output Source Current vs Output Voltage (V_{CC}=5V)

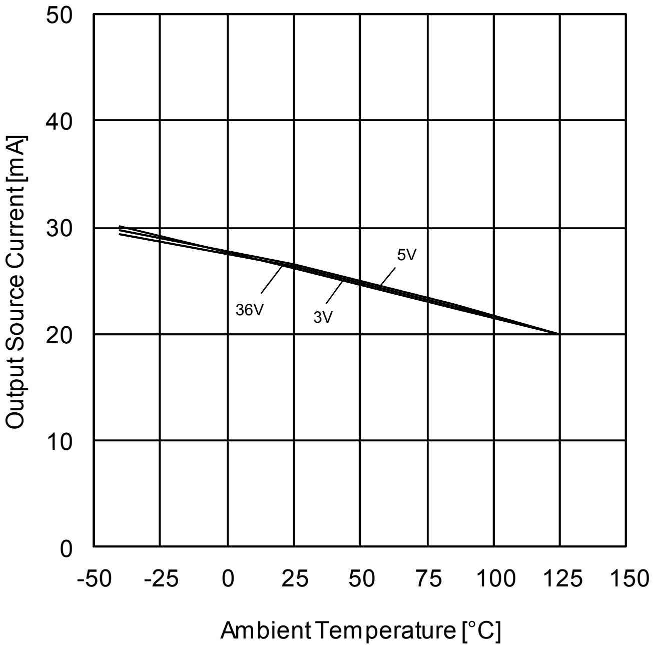


Figure 36. Output Source Current vs Ambient Temperature (V_{OUT}=0V)

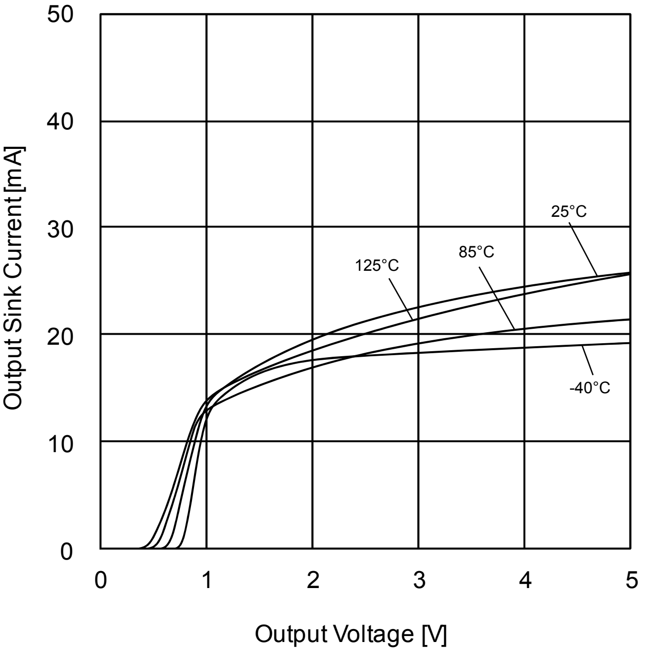


Figure 37. Output Sink Current vs Output Voltage (V_{CC}=5V)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM324xxx, LM2902xxx

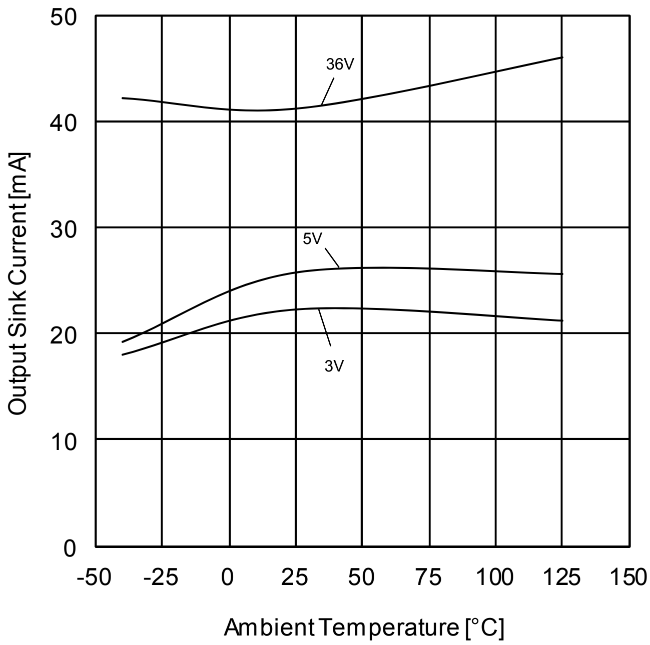


Figure 38. Output Sink Current vs Ambient Temperature (V_{OUT}=V_{CC})

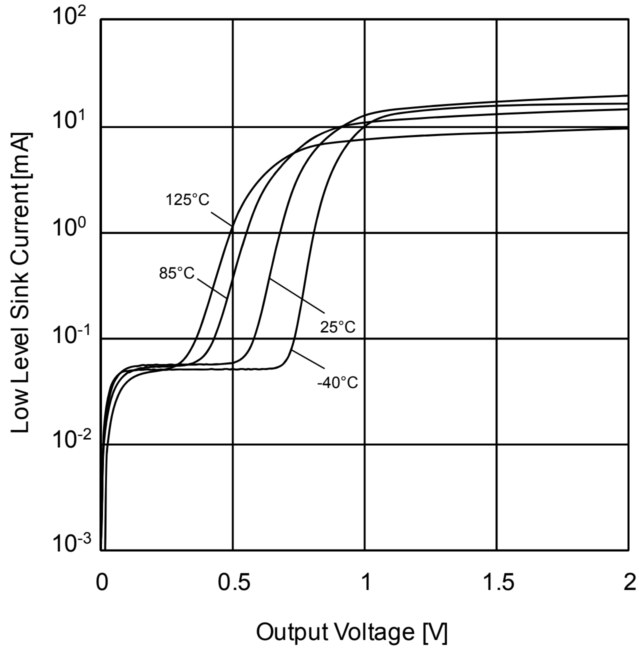


Figure 39. Low Level Sink Current vs Output Voltage (V_{CC}=5V)

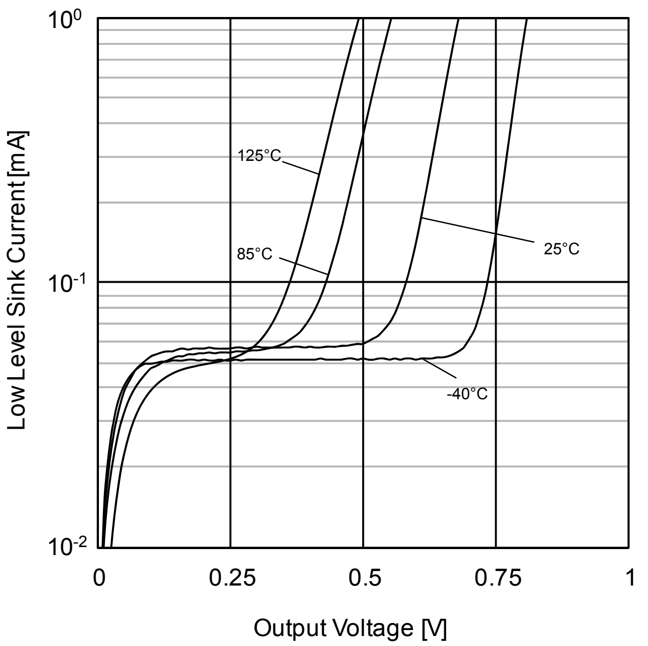


Figure 40. Low Level Sink Current vs Output Voltage (Enlarged view) (V_{CC}=5V)

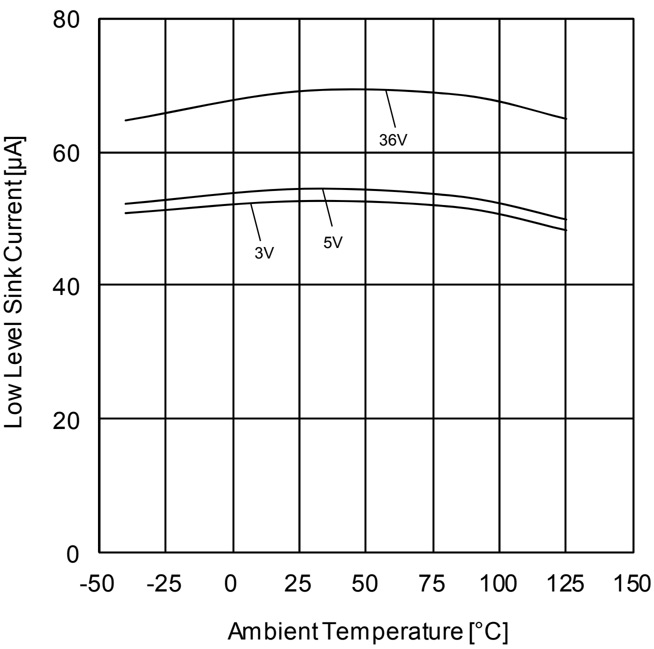


Figure 41. Low Level Sink Current vs Ambient Temperature (V_{OUT}=200mV)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Typical Performance Curves - continued

○**LM324xxx, LM2902xxx**

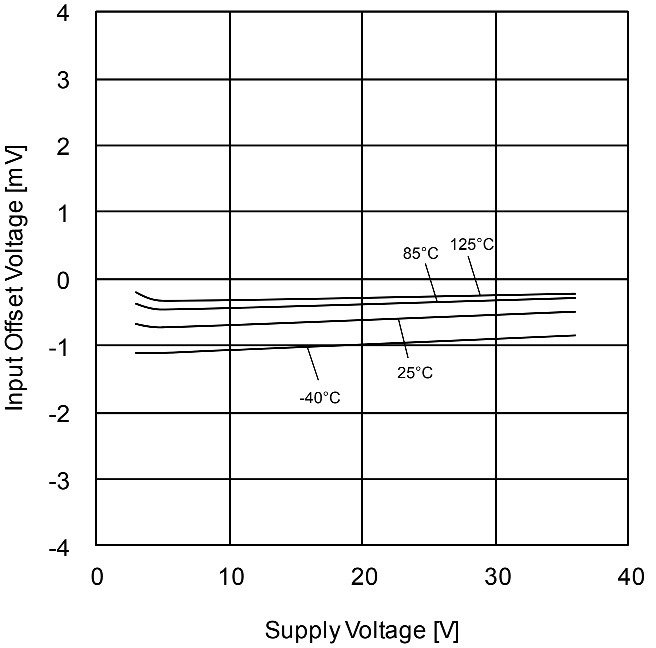


Figure 42. Input Offset Voltage vs Supply Voltage (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

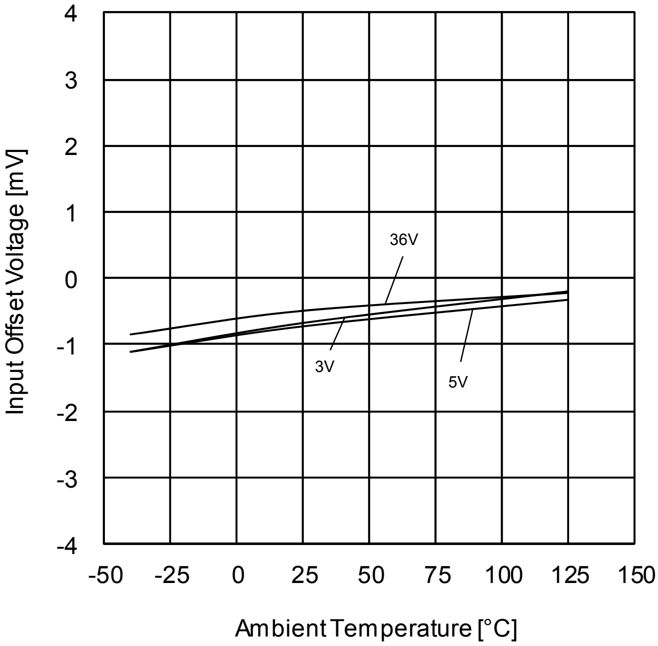


Figure 43. Input Offset Voltage vs Ambient Temperature (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

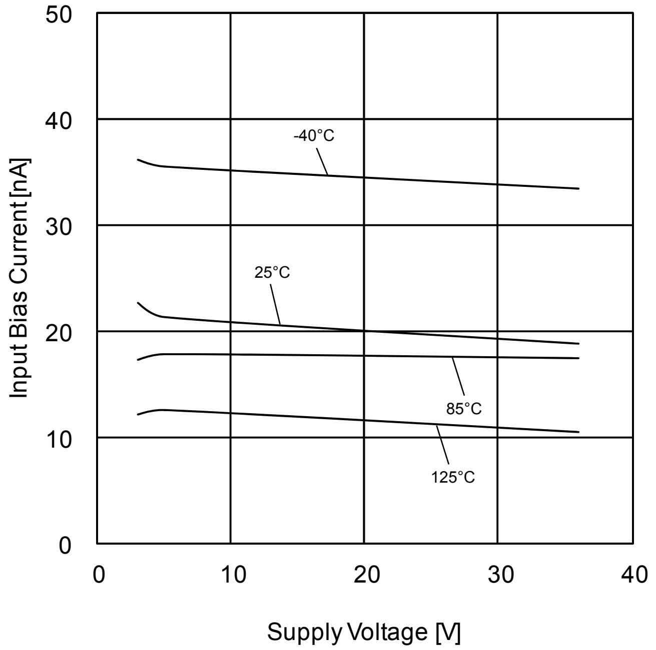


Figure 44. Input Bias Current vs Supply Voltage (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

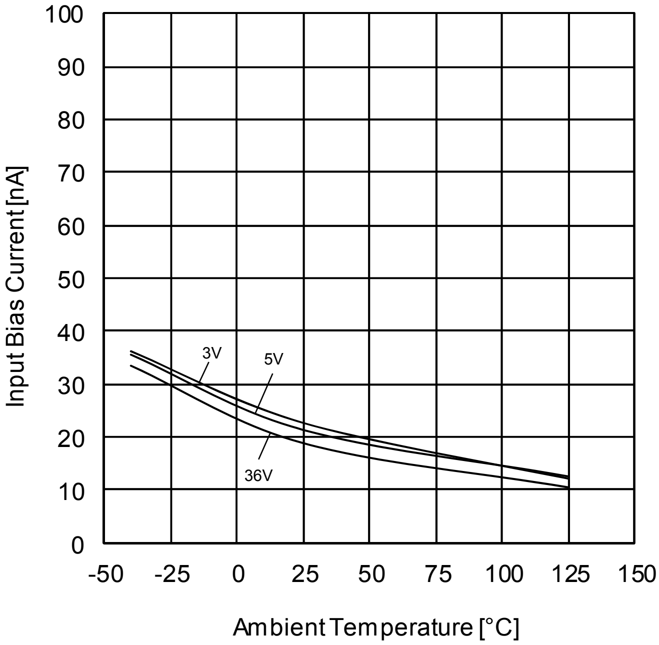


Figure 45. Input Bias Current vs Ambient Temperature (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM324xxx, LM2902xxx

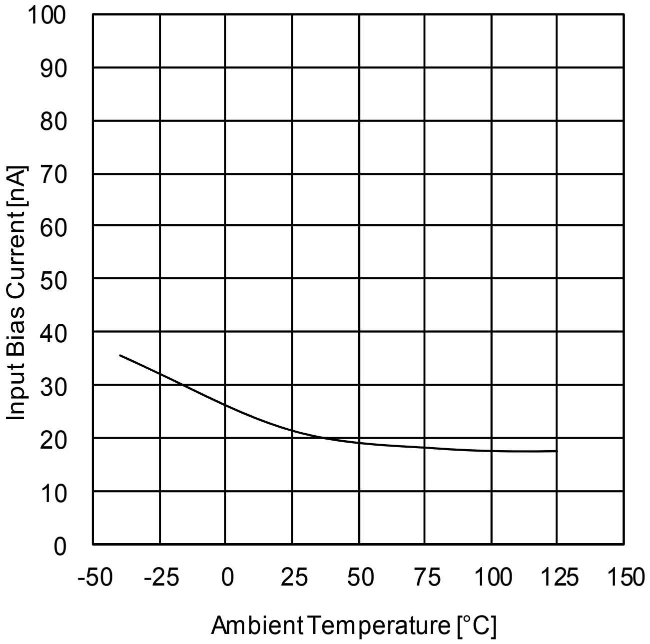


Figure 46. Input Bias Current vs Ambient Temperature (V_{CC}=30V, V_{ICM}=28V, E_K=-1.4V)

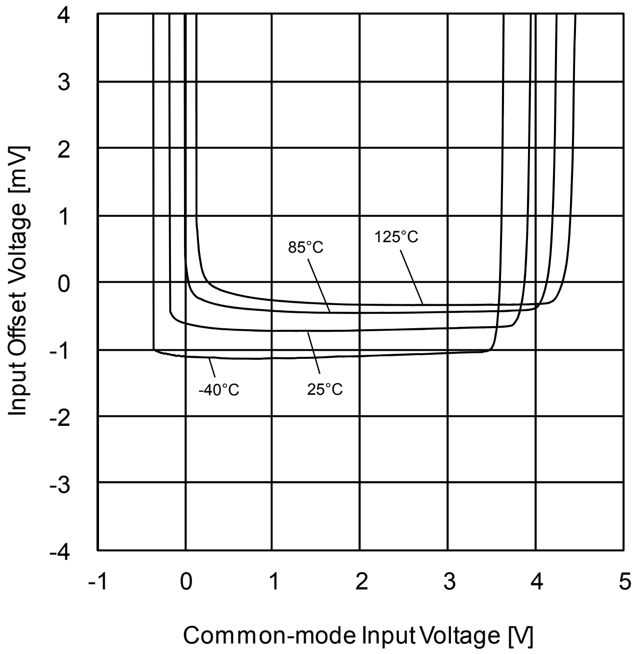


Figure 47. Input Offset Voltage vs Common-mode Input Voltage (V_{CC}=5V)

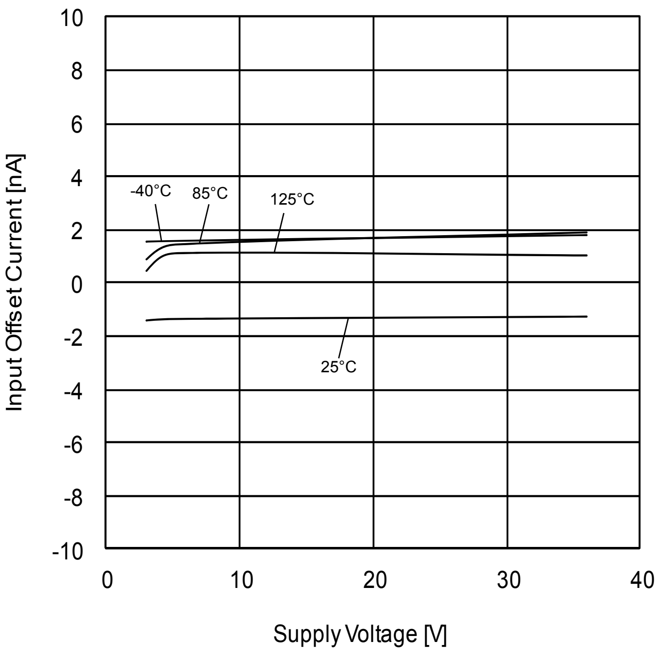


Figure 48. Input Offset Current vs Supply Voltage (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

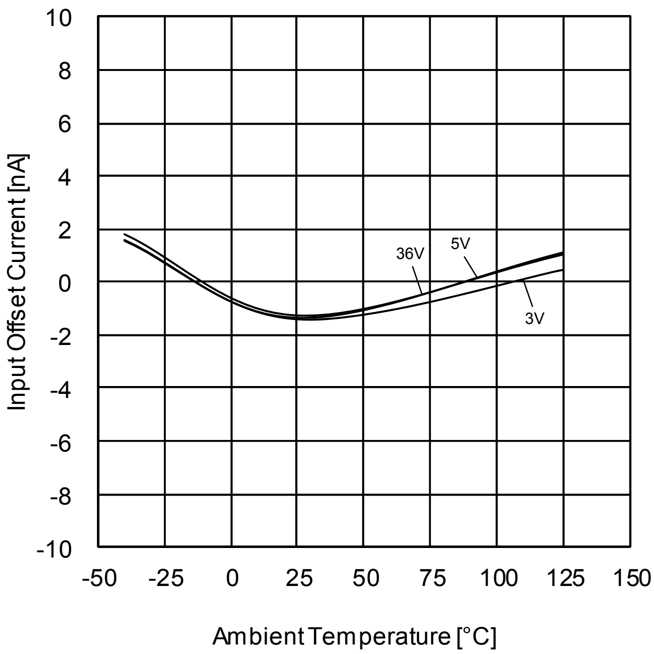


Figure 49. Input Offset Current vs Ambient Temperature (V_{ICM}=V_{CC}/2, E_K=-V_{CC}/2)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Typical Performance Curves - continued

○LM324xxx, LM2902xxx

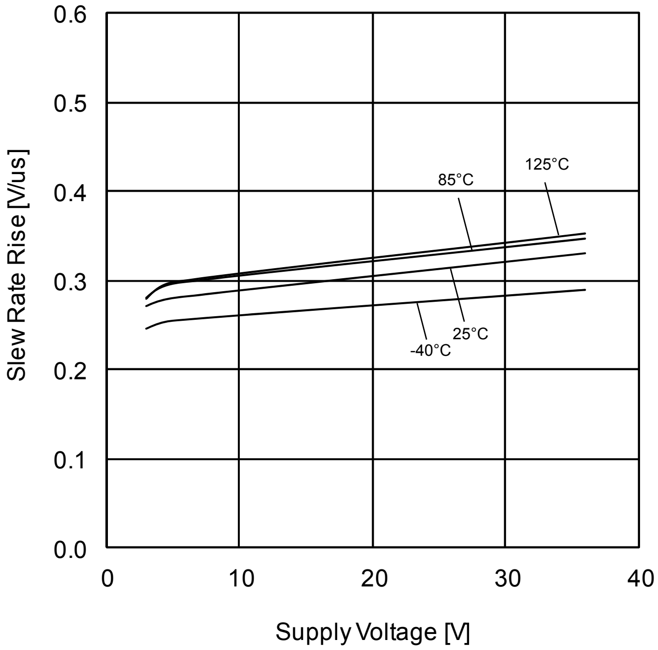


Figure 50. Slew Rate Rise vs Supply Voltage (R_L=2kΩ, Low to High)

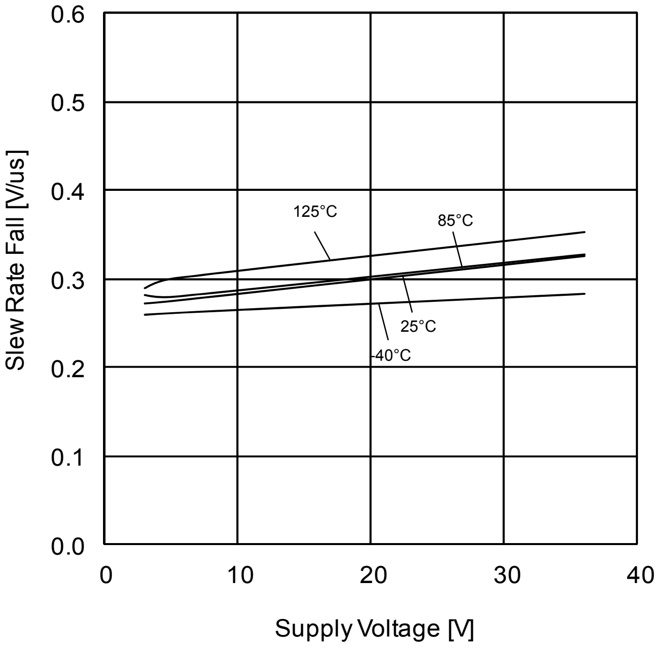


Figure 51. Slew Rate Fall vs Supply Voltage (R_L=2kΩ, High to Low)

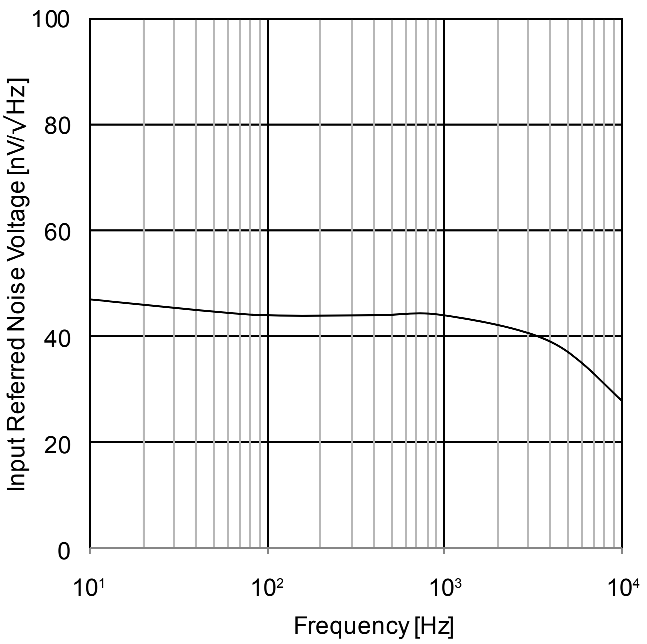


Figure 52. Input Referred Noise Voltage vs Frequency (V_{CC}=5V)

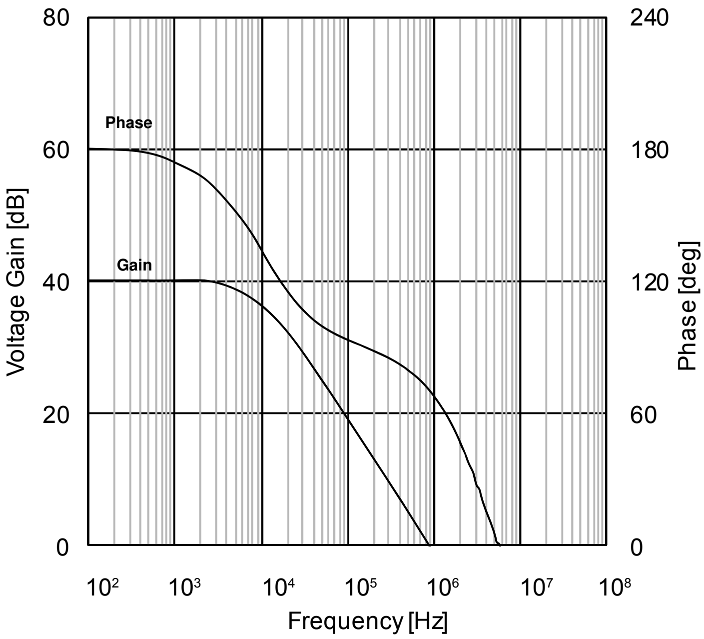


Figure 53. Voltage Gain, Phase vs Frequency (V_{CC}=30V, R_L=2kΩ, C_L=100pF)

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Typical Performance Curves - continued

○**LM324xxx, LM2902xxx**

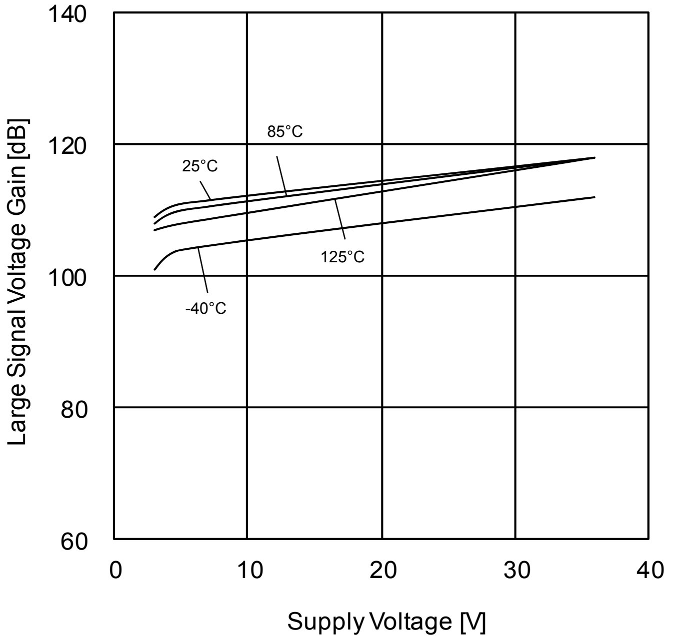


Figure 54. Large Signal Voltage Gain vs Supply Voltage (R_L=2kΩ)

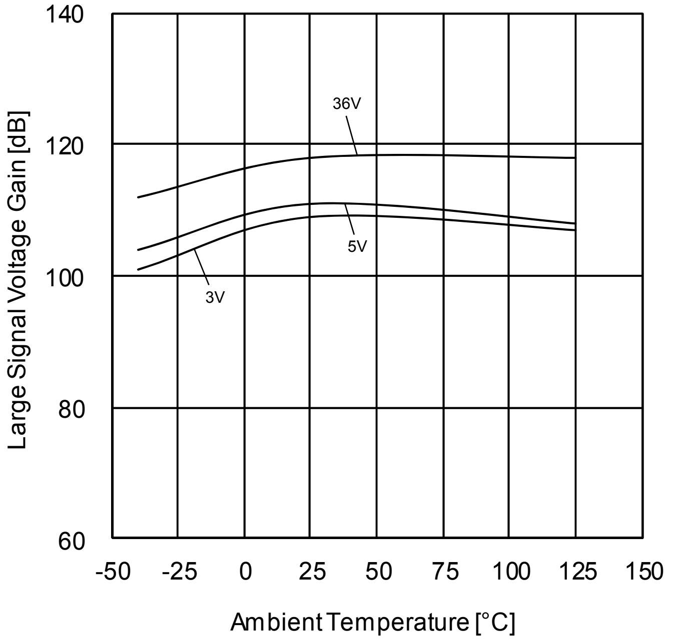


Figure 55. Large Signal Voltage Gain vs Ambient Temperature (R_L=2kΩ)

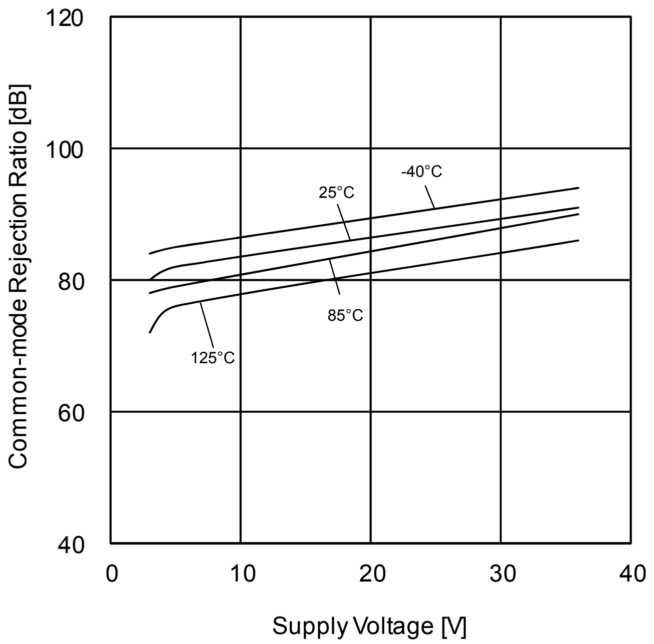


Figure 56. Common-mode Rejection Ratio vs Supply Voltage

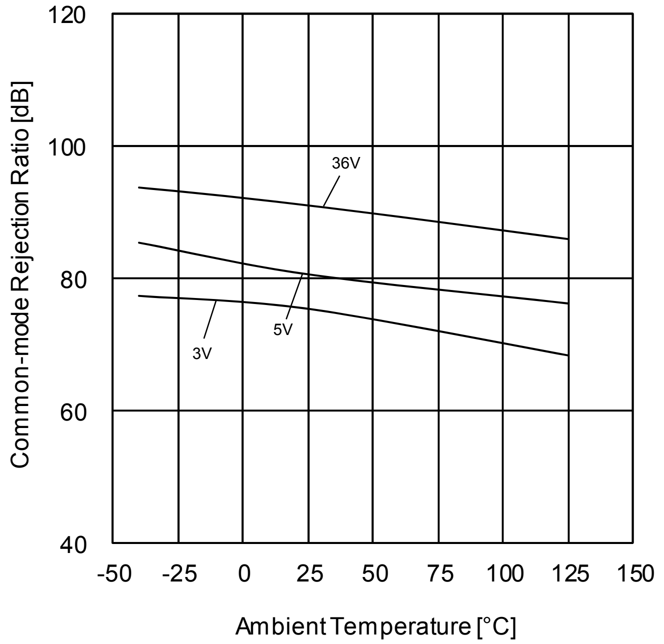


Figure 57. Common-mode Rejection Ratio vs Ambient Temperature

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Typical Performance Curves - continued

○**LM324xxx, LM2902xxx**

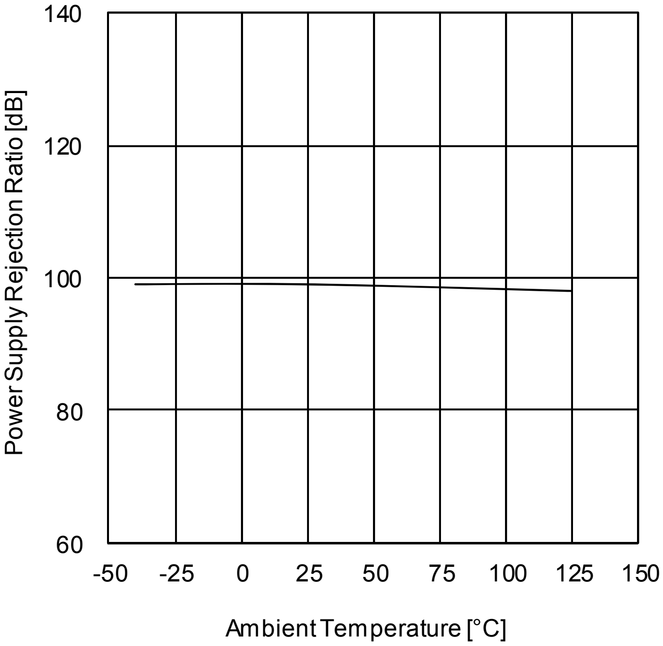


Figure 58. Power Supply Rejection Ratio vs Ambient Temperature

(*) The above data are measurement value of typical sample, they are not guaranteed.
LM324xxx: -40°C to +85°C LM2902xxx: -40°C to 125°C

Application Information

NULL method condition for Test Circuit 1

V_{CC}, V_{EE}, E_K, V_{ICM} Unit: V

Parameter	V_F	SW1	SW2	SW3	V_{CC}	V_{EE}	E_K	V_{ICM}	Calculation
Input Offset Voltage	V_{F1}	ON	ON	OFF	5 to 30	0	-1.4	0	1
Input Offset Current	V_{F2}	OFF	OFF	OFF	5	0	-1.4	0	2
Input Bias Current	V_{F3}	OFF	ON	OFF	5	0	-1.4	0	3
	V_{F4}	ON	OFF						
Large Signal Voltage Gain	V_{F5}	ON	ON	ON	15	0	-1.4	0	4
	V_{F6}						-11.4		
Common-mode Rejection Ratio (Input Common-mode Voltage Range)	V_{F7}	ON	ON	OFF	5	0	-1.4	0	5
	V_{F8}							3.5	
Power Supply Rejection Ratio	V_{F9}	ON	ON	OFF	5	0	-1.4	0	6
	V_{F10}				30				

- Calculation -

1. Input Offset Voltage (V_{IO})

$$V_{IO} = \frac{|V_{F1}|}{1 + R_F/R_S} \quad [V]$$

2. Input Offset Current (I_{IO})

$$I_{IO} = \frac{|V_{F2} - V_{F1}|}{R_I \times (1 + R_F/R_S)} \quad [A]$$

3. Input Bias Current (I_B)

$$I_B = \frac{|V_{F4} - V_{F3}|}{2 \times R_I \times (1 + R_F/R_S)} \quad [A]$$

4. Large Signal Voltage Gain (A_V)

$$Av = 20Log \frac{\Delta E_K \times (1+R_F/R_S)}{|V_{F6} - V_{F5}|} \quad [dB]$$

5. Common-mode Rejection Ratio (CMRR)

$$CMRR = 20Log \frac{\Delta V_{ICM} \times (1+R_F/R_S)}{|V_{F8} - V_{F7}|} \quad [dB]$$

6. Power Supply Rejection Ratio (PSRR)

$$PSRR = 20Log \frac{\Delta VCC \times (1+ R_F/R_S)}{|V_{F10} - V_{F9}|} \quad [dB]$$

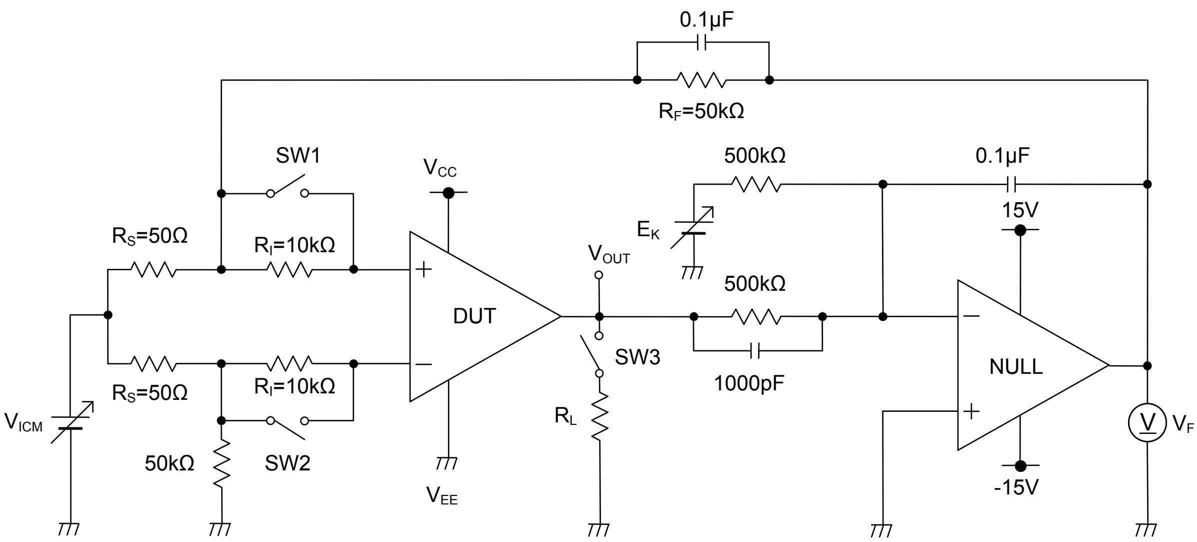


Figure 59. Test Circuit 1 (One Channel Only)

Application Information – continued

Switch Condition for Test Circuit 2

Parameter	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13
Supply Current	OFF	OFF	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Maximum Output Voltage(High)	OFF	OFF	ON	OFF	OFF	ON	OFF	OFF	ON	OFF	OFF	ON	OFF
Maximum Output Voltage(Low)	OFF	OFF	ON	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF
Output Source Current	OFF	OFF	ON	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	ON
Output Sink Current	OFF	OFF	ON	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	ON
Slew Rate	OFF	OFF	OFF	ON	OFF	OFF	OFF	ON	ON	ON	OFF	OFF	OFF
Gain Bandwidth Product	OFF	ON	OFF	OFF	ON	ON	OFF	OFF	ON	ON	OFF	OFF	OFF
Input Referred Noise Voltage	ON	OFF	OFF	OFF	ON	ON	OFF	OFF	OFF	OFF	ON	OFF	OFF

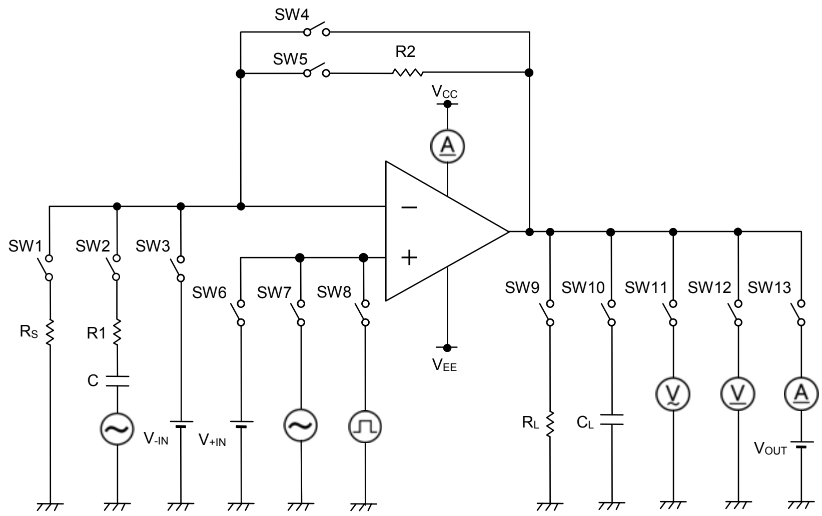


Figure 60. Test Circuit 2 (Each Op-Amp)

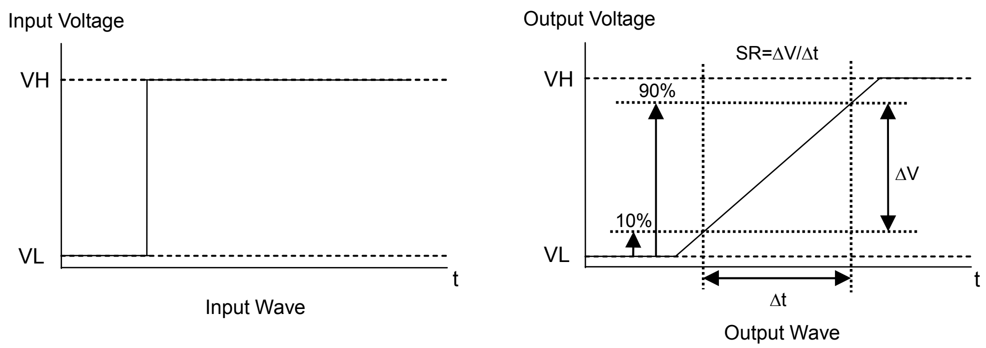


Figure 61. Slew Rate Input and Output Wave

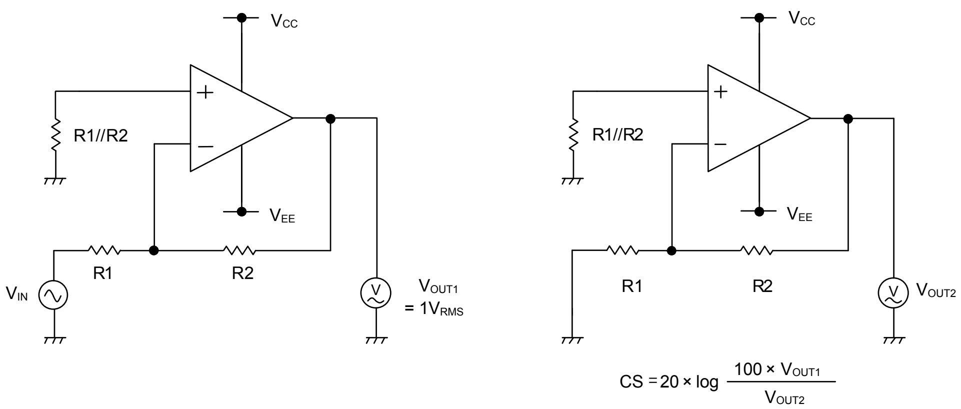


Figure 62. Test Circuit 3 (Channel Separation)
(R1=1kΩ,R2=100kΩ)

Application Information – continued

1. **Unused Circuits**
   It is recommended to apply the connection (see Figure 63) and set the non-inverting input pin at a potential within the Input Common-mode Voltage Range (V_{ICM}) for any unused circuit.

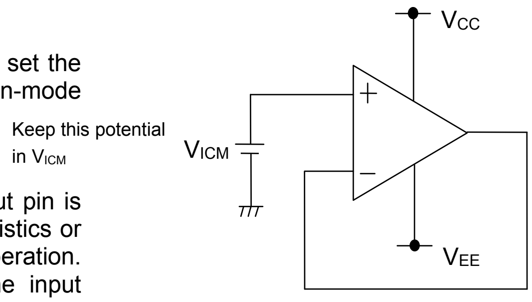


Figure 63. The Example of Application Circuit for Unused Op-amp

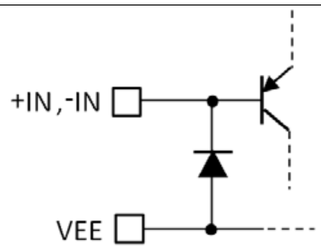
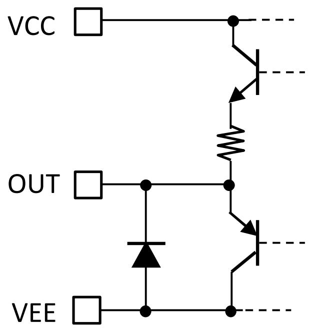
2. **Input Voltage**
   Regardless of the supply voltage, applying V_{EE}+36V to the input pin is possible without causing deterioration of the electrical characteristics or destruction. However, this does not ensure normal circuit operation. Please note that the circuit operates normally only when the input voltage is within the common mode input voltage range of the electric characteristics.

3. **Power Supply (Single/Dual)**
   The operational amplifiers operate when the voltage supplied is between VCC pin and VEE pin. Therefore, the single supply operational amplifiers can be used as dual supply operational amplifiers as well.

4. **IC Handling**
   When pressure is applied to the IC through warp on the printed circuit board, the characteristics may fluctuate due to the piezo effect. Be careful with the warp on the printed circuit board.

5. **The IC Destruction Caused by Capacitive Load**
   The IC may be damaged when VCC pin and VEE pin is shorted with the charged output pin capacitor. When IC is used as an operational amplifier or as an application circuit where oscillation is not activated by an output capacitor, output capacitor must be kept below 0.1µF in order to prevent the damage mentioned above.

I/O Equivalent Circuit

Symbol	Pin No.	Equivalent Circuit
+IN -IN	LM358xxx, LM2904xxx: 2,3,5,6 LM324xxx, LM2902xxx: 2,3,5,6,9,10,12,13	
OUT	LM358xxx, LM2904xxx: 1,7 LM324xxx, LM2902xxx: 1,7,8,14	
VCC	LM358xxx, LM2904xxx: 8 LM324xxx, LM2902xxx: 4