

## Op-Amp Crash Course Part 2: Key Parameters

A circuit designer selects an op-amp based on several device parameters. These parameters must satisfy the requirements of the application the op-amp is used in. The most frequently considered parameters are listed below.

Part 2 of this tutorial explains their definitions and purposes.

### Contents

1.	<b>Op-amp Gain versus Amplifier Circuit Gain</b>	2
2.	<b>Gain Bandwidth (GBW)</b>	3
3.	<b>Input Offset Voltage (<math>V_{OS}</math>)</b>	4
4.	<b>Supply Current per Channel (ICC)</b>	5
5.	<b>Supply Voltage Range (VCC)</b>	6
6.	<b>Rail-to-Rail Input/Output Range (RR-I/O)</b>	6
7.	<b>Conclusion</b>	6
8.	<b>Revision History</b>	6
A.	<b>Appendix</b>	7
A.1	Standard Op-amps: GBW < 50MHz	7
A.2	High-speed Op-amps: GBW ≥ 50MHz	9
A.3	Precision Op-amps: $V_{OS-MAX} \leq 0.5mV$	10
A.4	General Purpose Op-amps: $V_{OS-MAX} > 0.5mV$	11
A.5	Micro-Power Op-amps: $I_s \leq 300\mu A$	12
A.6	Low-Power Op-amps: $0.3mA \leq I_s \leq 1mA$	12
A.7	Low-Voltage Op-amps: $V_{s-max} < 6V$	13
A.8	High-Voltage Op-amps: $V_{s-max} > 6V$	14
A.9	Rail-to-Rail Input/Output Op-amps	15

# 1. Op-amp Gain versus Amplifier Circuit Gain

From Part 1, recall that a complete amplifier circuit (or amplifier configuration) always consists of the op-amp and its surrounding components, which determine the gain of the amplifier circuit. In the non-inverting amplifier of Figure 1, resistors  $R_1$  and  $R_2$  perform this task.

While the actual op-amp gain might be 100000 ( $10^5$ ), the gain of the amplifier circuit is set by the ratio of the resistor values, which might only be ten (10). Therefore, distinguish between two gain terms: the op-amp gain,  $A$ , and the amplifier circuit gain,  $G$ .

The op-amp gain is the ratio of the signal output voltage to the voltage difference at the op-amp inputs:

$$A = \frac{V_{OUT}}{V_{ID}}$$

The circuit gain is the ratio of the signal output voltage to the signal input voltage at the circuit input:

$$G = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2}{R_1}$$

In op-amp terminology the op-amp gain is the Open-Loop gain,  $A_{OL}$ , and the circuit gain is the Closed-Loop gain,  $A_{CL}$ .

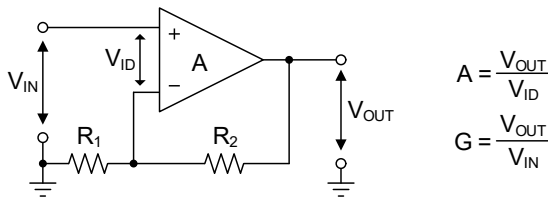


Figure 1. Non-inverting Amplifier

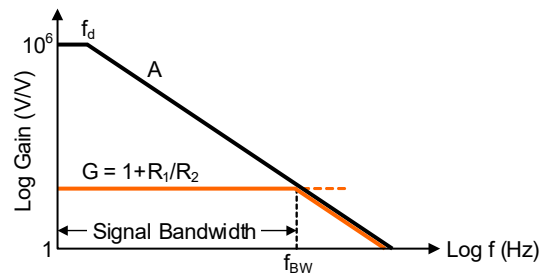


Figure 2. Op-amp Gain ( $A$ ) vs Circuit Gain ( $G$ )

Figure 2 shows the frequency responses of the op-amp gain,  $A$ , and the circuit gain,  $G$ . The op-amp gain is frequency dependent. It is very high from DC up to a certain frequency,  $f_d$ . Then it drops at a constant rate until it reaches a value of 1.

The op-amp gain represents an amplifier circuit design's maximum achievable gain setting. Gain settings beyond the op-amp gain response cannot be achieved.

This becomes clear when following the circuit gain response,  $G$ , which remains constant over a wide frequency range until it reaches the op-amp gain response at the bandwidth frequency,  $f_{BW}$ . Beyond  $f_{BW}$ , the circuit gain follows the op-amp gain response, as the op-amp cannot support gains higher than its own.

- The frequency,  $f_{BW}$ , is the upper limit of the signal frequency bandwidth.
- The signal frequency bandwidth is the range of signal frequencies from DC up to  $f_{BW}$ , which the amplifier circuit can amplify at a given circuit gain,  $G$ .

## 2. Gain Bandwidth (GBW)

As the gain axis and the frequency axis have a logarithmic scale, the slope of the op-amp gain beyond  $f_d$  is constant, and each point on this slope represents a constant product of circuit gain  $\times$  signal frequency bandwidth. Hence, the name gain-bandwidth product, or GBW.

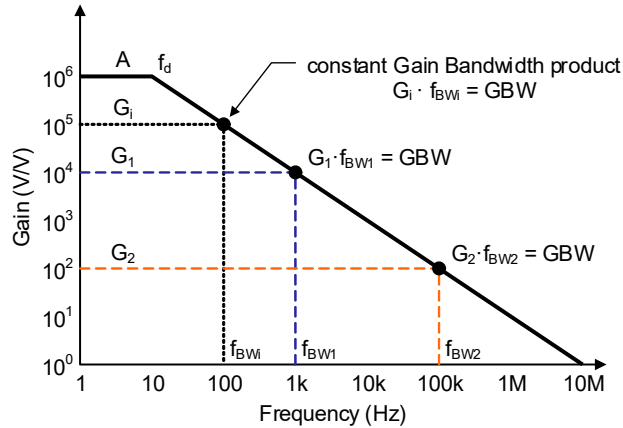


Figure 3. Gain-Bandwidth Product:  $GBW = G_i \cdot f_{BW_i} = \text{constant}$

The GBW of an op-amp determines the maximum possible signal bandwidth an op-amp can support for a given gain setting:

$$GBW = G_i \times f_{BW_i}$$

For example, if the non-inverting amplifier in [Figure 1](#) has a circuit gain of  $G_1 = 100$  and the op-amp has a GBW of 1MHz, then the maximum signal bandwidth of this amplifier is:

$$f_{BW1} = \frac{GBW}{G_1} = \frac{1\text{MHz}}{100} = 10\text{kHz}$$

If the circuit gain is lowered to  $G_2 = 10$ , the maximum signal bandwidth increases to:

$$f_{BW2} = \frac{GBW}{G_2} = \frac{1\text{MHz}}{10} = 100\text{kHz}$$

Therefore, the gain bandwidth product of an op-amp determines the maximum possible signal bandwidth of an amplifier circuit for a given circuit gain.

Op-amp manufacturers mainly distinguish between high-speed op-amps ( $GBW \geq 50\text{MHz}$ ) and non-high-speed or standard op-amps:

- Standard amplifiers with  $GBW < 50\text{MHz}$
- High-speed amplifiers with  $GBW \geq 50\text{MHz}$

See [Appendix A.1](#) and [A.2](#) for the standard and high-speed op-amps lists.

### 3. Input Offset Voltage ( $V_{OS}$ )

Every op-amp has an internal DC error voltage, known as the input offset voltage,  $V_{OS}$ , which causes it to output a voltage even if its inputs are zero.

Figure 4 shows the model of a practical op-amp, where  $V_{OS}$  is assigned to the positive input of an ideal op-amp (without offset). As the input offset is in series with the signal input,  $V_{OS}$  adds to  $V_{IN}$ , causing an input error. The effective input voltage,  $V_{IN} + V_{OS}$ , is then amplified by the gain of the amplifier circuit, resulting in an even larger output offset error.

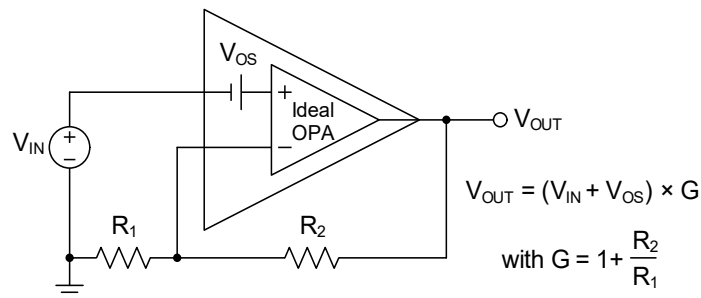


Figure 4.  $V_{OS}$  causes an Input Error that the Circuit Gain Amplifies

The input offset voltages for various op-amps can range from as little as  $2\mu\text{V}$  up to as much as  $10\text{mV}$ , spanning more than three decades or a factor of 1000.

Op-amp manufacturers, therefore, distinguish between general-purpose and precision op-amps.

Precision op-amps are those with  $V_{OS} \leq 0.5\text{mV}$ , and general-purpose op-amps with  $V_{OS} > 0.5\text{mV}$ .

Whether an amplifier design requires a precision op-amp or can do with a general-purpose device depends on the required accuracy of the application. After budgeting the error due to resistor tolerances, the other main error source is the input signal error due to input offset.

An amplifier with large signal input, such as in the hundreds of millivolts, might utilize an op-amp whose  $V_{OS}$  is in the millivolt range (ISL28213:  $V_{OS} = 4\text{mV}$ ). However, in the case of a small input signal, such as in the hundreds of microvolts, the amplifier design requires a precision op-amp with a  $V_{OS}$  in the microvolt range (ISL28233:  $V_{OS} = 40\mu\text{V}$ ). Therefore, memorize that the lower the op-amp input offset voltage,  $V_{OS}$ , the higher the accuracy of the amplifier design.

See Appendix A.3 and A.4 for the Precision and General-Purpose op-amps lists.

## 4. Supply Current per Channel ( $I_{CC}$ )

Every op-amp needs a certain amount of current to sufficiently bias its internal transistors for correct operation (Figure 5). This current is the supply current,  $I_{CC}$ . It is specified for a single channel only to allow for proper supply-current comparison between single, dual, and quad-channel devices.  $I_{CC}$  is measured with the op-amp operating in the unity-gain or buffer configuration (Figure 6), under no-load condition ( $I_{OUT} = 0A$ ), and with the signal input being grounded ( $V_{IN} = 0V$ ).

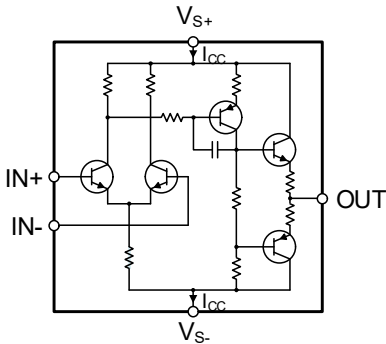


Figure 5.  $I_{CC}$  biases internal Transistors

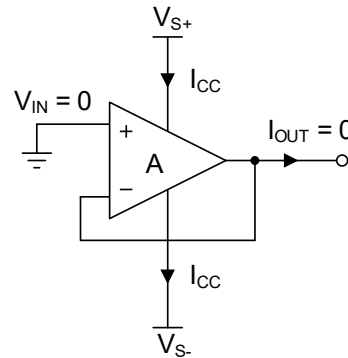


Figure 6.  $I_{CC}$  Test Conditions

The product of supply current times the nominal supply voltage leads to the differentiation between fast op-amps and low-power op-amps, and within the low-power category, between micro-power and nano-power op-amps.

Fast op-amps with high gain bandwidth and high slew rate require larger, fast-switching transistors with large bias currents. This results in supply currents that are significantly higher than those of low-power op-amps.

In contrast, low-power op amps use smaller transistors with weaker biasing, which drastically reduces the total supply current. These op-amps offer a variety of benefits in many applications.

- In multi-channel data acquisition systems, low-power op-amps allow for a much denser device population without creating heat gradients. At the same time, they reduce total system power consumption and cost.
- In single-channel applications, their low supply current reduces self-heating, which minimizes thermally induced input offset shift.
- In battery-powered applications, devices with very low supply currents prolong battery life.

However, with the reduction in supply currents comes a trade-off in the form of lower bandwidth. Table 1 compares various op-amps from high to low and ultra-low supply currents.

Table 1.  $I_{CC}$  per Channel versus Gain Bandwidth and Noise

Parameter	Symbol	ISL28191	ISL28114	ISL28113	ISL28133
Supply Voltage	$V_{CC}$	3.0V – 5.5V	1.8V – 5.5V	1.8V – 5.5V	1.8V – 5.5V
Supply Current per Channel	$I_{CC}$	2.6mA	300 $\mu$ A	90 $\mu$ A	18 $\mu$ A
Bandwidth	GBW	61MHz	5MHz	2MHz	400kHz

Op-amp manufacturers distinguish between low-power and micro-power op-amps by their supply currents. Low-power op-amps have an  $I_{CC} \leq 1mA$ , and micro-power devices have an  $I_{CC} \leq 500\mu A$ .

See Appendix A.5 and A.6 for the micro-power and low-power op-amps lists.

## 5. Supply Voltage Range ( $V_{CC}$ )

Op-amps are used in various industrial applications, ranging from low-voltage data acquisition systems to high-voltage signal conditioners. Amongst these applications, two major voltage categories developed, leading to the development of op-amps with the following corresponding supply voltage ranges:

- Low voltage op-amps with  $V_{CC} \leq 6V$
- High voltage op-amps with  $V_{CC} > 6V$

See Appendix A.7 and A.8 for the low-voltage and high-voltage op-amps lists.

## 6. Rail-to-Rail Input/Output Range (RR-I/O)

An op-amp's positive and negative supply voltages are known as supply rails or rails for short.

Early op-amp designs required supply voltages of  $\pm 15V$  to  $\pm 18V$ . They had input and output voltage ranges with upper and lower limits of a couple or more volts below the positive and above the negative supply rail. These ranges are depicted as  $V_{IN1}$  and  $V_{OUT1}$  in Figure 7.

Later design generations allowed for lower supply voltages of  $\pm 12V$  and also provided an extended input voltage range that included the negative supply rail, represented by  $V_{IN2}$ .

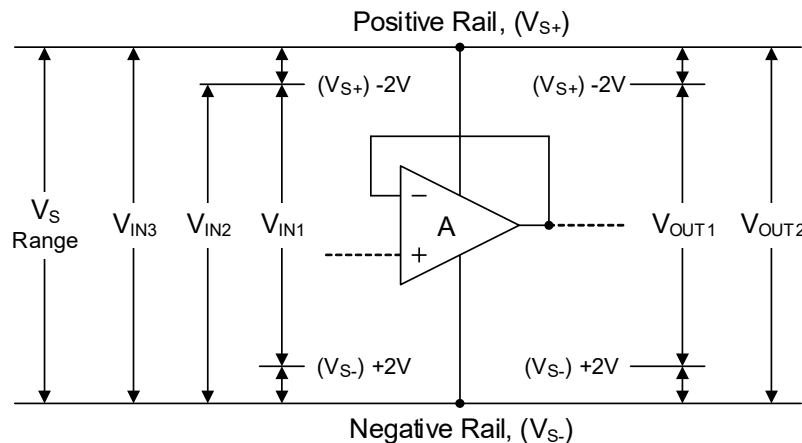


Figure 7. Possible Op-amp Input and Output Voltage Ranges

The ongoing trend towards smaller supply voltages of 5V and even 1.8V required op-amps to have input and output voltage ranges that span the entire supply voltage range ( $V_{IN3}$  and  $V_{OUT2}$  in Figure 7). Hence, the name rail-to-rail input, rail-to-rail output, or rail-to-rail input/output (RR-I/O) op-amp.

See Appendix A.9 for a list of op-amps with rail-to-rail input/output ranges.

## 7. Conclusion

Part 2 explained the key device parameters circuit designers consider when selecting op-amps for their applications. While a new parametric search engine is in the planning stage, an interim solution in the form of lists of op-amp categories is included in the following appendices.

## 8. Revision History

Revision	Date	Description
1.00	May 11, 2023	Initial release.

## A. Appendix

### A.1 Standard Op-amps: GBW < 50MHz

Part Number	Ch (#)	V <sub>s</sub> (Min) (V)	V <sub>s</sub> (Max) (V)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	V <sub>os</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	I <sub>S</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
ISL28130	1	1.8	5.5	0.4	0.1	65	0.04	250	0.02	15	-40	125	5	SC70, SOT23
ISL28133	1	1.8	5.5	0.4	0.1	65	0.008	300	0.018	17	-40	125	5	SC70, SOT23
ISL28230	2	1.8	5.5	0.4	0.1	65	0.04	250	0.02	15	-40	125	8	DFN, MSOP, SOICN
ISL28233	2	1.8	6	0.4	0.2	65	0.006	180	0.018	17	-40	125	8	DFN, MSOP, SOICN
ISL28430	4	1.8	5.5	0.4	0.1	65	0.04	250	0.02	15	-40	125	14	SOICN, TSSOP
ISL28433	4	1.8	5.5	0.4	0.1	65	0.008	300	0.018	17	-40	125	14	SOICN, TSSOP
READ2303G	2	1.8	5.5	0.55	0.35	-	6	1	0.04	10	-40	105	8	MSOP, TSSOP
READ2351J	2	1.8	5.5	0.55	0.35	-	6	1	0.04	10	-40	125	8	TSSOP
READ2353J	2	1.8	5.5	0.55	0.35	-	6	1	0.04	10	-40	125	8	TSSOP
READ4303G	4	1.8	5.5	0.55	0.35	-	6	1	0.04	10	-40	105	14	TSSOP
ISL28177	1	6	40	0.6	0.2	9.5	0.15	1000	1.18	30	-40	125	8	SOICN
ISL28207	2	4.5	40	1	0.32	13	0.075	300	0.21	40	-40	125	8	SOICN
ISL28108	1	3	40	1.2	0.45	15.8	0.15	-13000	0.185	19	-40	125	8	SOICN
ISL28208	2	3	40	1.2	0.45	15.8	0.23	-13000	0.185	19	-40	125	8	MSOP, SOICN
ISL28217	2	4.5	40	1.5	0.5	8	0.05	1000	0.44	43	-40	125	8	MSOP, SOICN
ISL28113	1	1.8	5.5	2	1	55	4	2	0.09	16	-40	125	5	SC70, SOT23
ISL28213	2	1.8	5.5	2	1	55	5	3	0.13	22	-40	125	8	MSOP, SOICN, SOT23
ISL28413	4	1.8	5.5	2	1	55	4	2	0.09	16	-40	125	14	SOICN, TSSOP
ISL28134	1	2.25	6	3.5	1	10	0.0025	300	0.675	65	-40	125	5, 8	SOICN, SOT23
ISL28118	1	3	40	4	1.2	5.6	0.15	-575000	0.85	16	-40	125	8	MSOP, SOICN
ISL28118M	1	3	40	4	1.2	5.6	0.15	-575000	0.85	16	-55	125	8	MSOP
ISL28218	2	3	40	4	1.2	5.6	0.23	-575000	0.85	16	-40	125	8	MSOP, SOICN
ISL28114	1	1.8	5.5	5	2.5	40	4	2	0.3	26	-40	125	5	SC70, SOT23
ISL28214	2	1.8	5.5	5	2.5	40	4	3	0.039	31	-40	125	8	MSOP, SOICN
ISL28414	4	1.8	5.5	5	2.5	40	4	2	0.3	26	-40	125	14	SOICN, TSSOP

## Op-Amp Crash Course Part 2: Key Parameters Tutorial

Part Number	Ch (#)	V <sub>S</sub> (Min) (V)	V <sub>S</sub> (Max) (V)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	V <sub>os</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	I <sub>S</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
READ2302G	2	2.5	5.5	6	8	-	6	1	0.82	20	-40	105	8	TSSOP
READ2304G	2	2.5	5.5	6	8	-	6	1	0.75	20	-40	105	8	MSOP, TSSOP
READ2352J	2	2.5	5.5	6	8	-	6	1	0.75	20	-40	125	8	TSSOP
READ2354J	2	2.5	5.5	6	8	-	6	1	0.75	20	-40	125	8	TSSOP
READ4304G	4	2.5	5.5	6	8	-	6	1	0.75	20	-40	105	14	TSSOP
ISL28227	2	4.5	40	10	3.6	2.5	0.075	10000	2.2	45	-40	125	8	MSOP, SOICN
ISL24021	1	4.5	19	12	19	190	15	10000	2.2	300	-40	85	8	TDFN
ISL28110	1	9	40	12.5	20	6	0.3	4.5	2.55	50	-40	125	8	SOICN
ISL28210	2	9	40	12.5	20	6	0.3	5	2.55	50	-40	125	8	SOICN



## A.2 High-speed Op-amps: $GBW \geq 50\text{MHz}$

Part Number	Ch (#)	V <sub>S</sub> (Min) (V)	V <sub>S</sub> (Max) (V)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	V <sub>OS</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	I <sub>S</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
EL5111	1	4.5	16.5	60	75	200	15	60	2.5	65	-40	85	5	TSOT
EL5111T	1	4.5	19	60	100	130	18	60	3.4	70	-40	85	5	TSOT
ISL28191	1	3	5.5	61	17	1.7	0.63	3000	2.6	130	-40	125	6	SOT23, μTDFN
ISL28291	2	3	5.5	61	17	1.7	0.63	3000	2.6	130	-40	125	8, 10	MSOP, SOICN, μTQFN
EL5160	1	5	10	200	1700	4	5	5000	0.75	70	-40	85	8, 6	SOICN, SOT23
EL5161	1	5	10	200	1700	4	5	5000	0.75	70	-40	85	5	SOT23
ISL55002	2	5	30	200	300	12	5	600	8.5	140	-40	85	8	SOICN
ISL55001	1	5	30	220	300	12	3	1720	9	145	-40	85	8	SOICN
HFA1105	1	9	11	330	1000	3.5	5	2000	5.8	60	-40	85	8	SOICN
EL5106	1	5	12	350	4500	2.8	10	1500	1.5	100	-40	85	6	SOT23
EL5306	3	5	12	350	4500	2.8	10	1500	1.5	100	-40	85	16	QSOP
HFA1135	1	9	11	360	1200	3.5	5	6000	6.9	60	-40	85	8	SOICN
EL5262	2	5	12	500	4000	3	5	2000	1.5	100	-40	85	10	MSOP
EL5263	2	5	12	500	2500	3	5	2000	1.5	100	-40	85	8	MSOP, SOICN
EL5462	4	5	12	500	4000	3	1.5	2000	1.5	100	-40	85	14	SOICN
HFA1130	1	9	11	850	2300	4	6	25000	21	60	-40	85	8	SOICN
EL5166	1	5	12	1400	6000	1.7	5	8500	8.5	160	-40	85	8, 6	SOICN, SOT23
ISL55210	1	3	4.2	2200	5600	0.85	1.4	50000	35	45	-40	85	16	TQFN

A.3 Precision Op-amps:  $V_{OS-MAX} \leq 0.5mV$ 

Part Number	Ch (#)	V <sub>s</sub> (Min) (V)	V <sub>s</sub> (Max) (V)	V <sub>OS</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	I <sub>s</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
ISL28134	1	2.25	6	0.0025	300	3.5	1	10	0.675	65	-40	125	5, 8	SOICN, SOT23
ISL28233	2	1.8	6	0.006	180	0.4	0.2	65	0.018	17	-40	125	8	DFN, MSOP, SOICN
ISL28133	1	1.8	5.5	0.008	300	0.4	0.1	65	0.018	17	-40	125	5	SC70, SOT23
ISL28433	4	1.8	5.5	0.008	300	0.4	0.1	65	0.018	17	-40	125	14	SOICN, TSSOP
ISL28130	1	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	5	SC70, SOT23
ISL28230	2	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	8	DFN, MSOP, SOICN
ISL28430	4	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	14	SOICN, TSSOP
ISL28217	2	4.5	40	0.05	1000	1.5	0.5	8	0.44	43	-40	125	8	MSOP, SOICN
ISL28207	2	4.5	40	0.075	300	1	0.32	13	0.21	40	-40	125	8	SOICN
ISL28227	2	4.5	40	0.075	10000	10	3.6	2.5	2.2	45	-40	125	8	MSOP, SOICN
ISL28108	1	3	40	0.15	-13000	1.2	0.45	15.8	0.185	19	-40	125	8	SOICN
ISL28118	1	3	40	0.15	-575000	4	1.2	5.6	0.85	16	-40	125	8	MSOP, SOICN
ISL28118M	1	3	40	0.15	-575000	4	1.2	5.6	0.85	16	-55	125	8	MSOP
ISL28177	1	6	40	0.15	1000	0.6	0.2	9.5	1.18	30	-40	125	8	SOICN
ISL28208	2	3	40	0.23	-13000	1.2	0.45	15.8	0.185	19	-40	125	8	MSOP, SOICN
ISL28218	2	3	40	0.23	-575000	4	1.2	5.6	0.85	16	-40	125	8	MSOP, SOICN
ISL28110	1	9	40	0.3	4.5	12.5	20	6	2.55	50	-40	125	8	SOICN
ISL28210	2	9	40	0.3	5	12.5	20	6	2.55	50	-40	125	8	SOICN

A.4 General Purpose Op-amps:  $V_{OS-MAX} > 0.5mV$ 

Part Number	Ch (#)	V <sub>S</sub> (Min) (V)	V <sub>S</sub> (Max) (V)	V <sub>OS</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	I <sub>S</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
ISL28113	1	1.8	5.5	4	2	2	1	55	0.09	16	-40	125	5	SC70, SOT23
ISL28114	1	1.8	5.5	4	2	5	2.5	40	0.3	26	-40	125	5	SC70, SOT23
ISL28214	2	1.8	5.5	4	3	5	2.5	40	0.039	31	-40	125	8	MSOP, SOICN
ISL28413	4	1.8	5.5	4	2	2	1	55	0.09	16	-40	125	14	SOICN, TSSOP
ISL28414	4	1.8	5.5	4	2	5	2.5	40	0.3	26	-40	125	14	SOICN, TSSOP
ISL28213	2	1.8	5.5	5	3	2	1	55	0.13	22	-40	125	8	MSOP, SOICN, SOT23
READ2302G	2	2.5	5.5	6	1	6	8	-	0.82	20	-40	105	8	TSSOP
READ2303G	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	105	8	MSOP, TSSOP
READ2304G	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	105	8	MSOP, TSSOP
READ2351J	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	125	8	TSSOP
READ2352J	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	125	8	TSSOP
READ2353J	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	125	8	TSSOP
READ2354J	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	125	8	TSSOP
READ4303G	4	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	105	14	TSSOP
READ4304G	4	2.5	5.5	6	1	6	8	-	0.75	20	-40	105	14	TSSOP
ISL24021	1	4.5	19	15	10000	12	19	190	2.2	300	-40	85	8	TDFN

## A.5 Micro-Power Op-amps: $I_s \leq 300\mu\text{A}$

Part Number	Ch (#)	V <sub>S</sub> (Min) (V)	V <sub>S</sub> (Max) (V)	I <sub>S</sub> /Ch (mA)	V <sub>OS</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
ISL28133	1	1.8	5.5	0.018	0.4	0.1	65	0.008	300	17	-40	125	5	SC70, SOT23
ISL28233	2	1.8	6	0.018	0.4	0.2	65	0.006	180	17	-40	125	8	DFN, MSOP, SOICN
ISL28433	4	1.8	5.5	0.018	0.4	0.1	65	0.008	300	17	-40	125	14	SOICN, TSSOP
ISL28130	1	1.8	5.5	0.02	0.4	0.1	65	0.04	250	15	-40	125	5	SC70, SOT23
ISL28230	2	1.8	5.5	0.02	0.4	0.1	65	0.04	250	15	-40	125	8	DFN, MSOP, SOICN
ISL28430	4	1.8	5.5	0.02	0.4	0.1	65	0.04	250	15	-40	125	14	SOICN, TSSOP
ISL28214	2	1.8	5.5	0.039	5	2.5	40	4	3	31	-40	125	8	MSOP, SOICN
READ2303G	2	1.8	5.5	0.04	0.55	0.35	-	6	1	10	-40	105	8	MSOP, TSSOP
READ2351J	2	1.8	5.5	0.04	0.55	0.35	-	6	1	10	-40	125	8	TSSOP
READ2353J	2	1.8	5.5	0.04	0.55	0.35	-	6	1	10	-40	125	8	TSSOP
READ4303G	4	1.8	5.5	0.04	0.55	0.35	-	6	1	10	-40	105	14	TSSOP
ISL28113	1	1.8	5.5	0.09	2	1	55	4	2	16	-40	125	5	SC70, SOT23
ISL28413	4	1.8	5.5	0.09	2	1	55	4	2	16	-40	125	14	SOICN, TSSOP
ISL28213	2	1.8	5.5	0.13	2	1	55	5	3	22	-40	125	8	MSOP, SOICN, SOT23
ISL28108	1	3	40	0.185	1.2	0.45	15.8	0.15	-13000	19	-40	125	8	SOICN
ISL28208	2	3	40	0.185	1.2	0.45	15.8	0.23	-13000	19	-40	125	8	MSOP, SOICN
ISL28207	2	4.5	40	0.21	1	0.32	13	0.075	300	40	-40	125	8	SOICN
ISL28114	1	1.8	5.5	0.3	5	2.5	40	4	2	26	-40	125	5	SC70, SOT23
ISL28414	4	1.8	5.5	0.3	5	2.5	40	4	2	26	-40	125	14	SOICN, TSSOP

## A.6 Low-Power Op-amps: $0.3\text{mA} \leq I_s \leq 1\text{mA}$

Part Number	Ch (#)	V <sub>S</sub> (Min) (V)	V <sub>S</sub> (Max) (V)	V <sub>OS</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	I <sub>S</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
ISL28217	2	4.5	40	0.44	1.5	0.5	8	0.05	1000	43	-40	125	8	MSOP, SOICN
ISL28134	1	2.25	6	0.675	3.5	1	10	0.0025	300	65	-40	125	5, 8	SOICN, SOT23
READ2304G	2	2.5	5.5	0.75	6	8	-	6	1	20	-40	105	8	MSOP, TSSOP
READ2352J	2	2.5	5.5	0.75	6	8	-	6	1	20	-40	125	8	TSSOP
READ2354J	2	2.5	5.5	0.75	6	8	-	6	1	20	-40	125	8	TSSOP
READ4304G	4	2.5	5.5	0.75	6	8	-	6	1	20	-40	105	14	TSSOP
READ2302G	2	2.5	5.5	0.82	6	8	-	6	1	20	-40	105	8	TSSOP
ISL28118	1	3	40	0.85	4	1.2	5.6	0.15	-575000	16	-40	125	8	MSOP, SOICN
ISL28118M	1	3	40	0.85	4	1.2	5.6	0.15	-575000	16	-55	125	8	MSOP
ISL28218	2	3	40	0.85	4	1.2	5.6	0.23	-575000	16	-40	125	8	MSOP, SOICN

A.7 Low-Voltage Op-amps:  $V_s\text{-max} < 6V$ 

Part Number	Ch (#)	V <sub>s</sub> (Min) (V)	V <sub>s</sub> (Max) (V)	V <sub>os</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	I <sub>s</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
ISL28113	1	1.8	5.5	4	2	2	1	55	0.09	16	-40	125	5	SC70, SOT23
ISL28114	1	1.8	5.5	4	2	5	2.5	40	0.3	26	-40	125	5	SC70, SOT23
ISL28130	1	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	5	SC70, SOT23
ISL28133	1	1.8	5.5	0.008	300	0.4	0.1	65	0.018	17	-40	125	5	SC70, SOT23
ISL28213	2	1.8	5.5	5	3	2	1	55	0.13	22	-40	125	8	MSOP, SOICN, SOT23
ISL28214	2	1.8	5.5	4	3	5	2.5	40	0.039	31	-40	125	8	MSOP, SOICN
ISL28230	2	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	8	DFN, MSOP, SOICN
ISL28413	4	1.8	5.5	4	2	2	1	55	0.09	16	-40	125	14	SOICN, TSSOP
ISL28414	4	1.8	5.5	4	2	5	2.5	40	0.3	26	-40	125	14	SOICN, TSSOP
ISL28430	4	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	14	SOICN, TSSOP
ISL28433	4	1.8	5.5	0.008	300	0.4	0.1	65	0.018	17	-40	125	14	SOICN, TSSOP
READ2302G	2	2.5	5.5	6	1	6	8	-	0.82	20	-40	105	8	TSSOP
READ2303G	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	105	8	MSOP, TSSOP
READ2304G	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	105	8	MSOP, TSSOP
READ2351J	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	125	8	TSSOP
READ2352J	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	125	8	TSSOP
READ2353J	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	125	8	TSSOP
READ2354J	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	125	8	TSSOP
READ4303G	4	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	105	14	TSSOP
READ4304G	4	2.5	5.5	6	1	6	8	-	0.75	20	-40	105	14	TSSOP
ISL28134	1	2.25	6	0.0025	300	3.5	1	10	0.675	65	-40	125	5, 8	SOICN, SOT23
ISL28233	2	1.8	6	0.006	180	0.4	0.2	65	0.018	17	-40	125	8	DFN, MSOP, SOICN

## A.8 High-Voltage Op-amps: $V_s\text{-max} > 6V$

Part Number	Ch (#)	$V_s$ (Min) (V)	$V_s$ (Max) (V)	$V_{os}$ (Max) (mV)	$I_B$ (Max) (pA)	GBW (MHz)	SR (V/ $\mu$ s)	$V_N$ (1kHz) (nV/ $\sqrt{\text{Hz}}$ )	$I_S$ /Ch (mA)	$I_O$ (mA)	Tmin (°C)	Tmax (°C)	Lead (#)	Pkg. Type
ISL28108	1	3	40	0.15	-13000	1.2	0.45	15.8	0.185	19	-40	125	8	SOICN
ISL28110	1	9	40	0.3	4.5	12.5	20	6	2.55	50	-40	125	8	SOICN
ISL28118	1	3	40	0.15	-575000	4	1.2	5.6	0.85	16	-40	125	8	MSOP, SOICN
ISL28118M	1	3	40	0.15	-575000	4	1.2	5.6	0.85	16	-55	125	8	MSOP
ISL28177	1	6	40	0.15	1000	0.6	0.2	9.5	1.18	30	-40	125	8	SOICN
ISL28207	2	4.5	40	0.075	300	1	0.32	13	0.21	40	-40	125	8	SOICN
ISL28208	2	3	40	0.23	-13000	1.2	0.45	15.8	0.185	19	-40	125	8	MSOP, SOICN
ISL28210	2	9	40	0.3	5	12.5	20	6	2.55	50	-40	125	8	SOICN
ISL28217	2	4.5	40	0.05	1000	1.5	0.5	8	0.44	43	-40	125	8	MSOP, SOICN
ISL28218	2	3	40	0.23	-575000	4	1.2	5.6	0.85	16	-40	125	8	MSOP, SOICN
ISL28227	2	4.5	40	0.075	10000	10	3.6	2.5	2.2	45	-40	125	8	MSOP, SOICN

## A.9 Rail-to-Rail Input/Output Op-amps

Part Number	Ch (#)	V <sub>S</sub> (Min) (V)	V <sub>S</sub> (Max) (V)	V <sub>OS</sub> (Max) (mV)	I <sub>B</sub> (Max) (pA)	GBW (MHz)	SR (V/μs)	V <sub>N</sub> (1kHz) (nV/√Hz)	I <sub>S</sub> /Ch (mA)	I <sub>O</sub> (mA)	T <sub>min</sub> (°C)	T <sub>max</sub> (°C)	Lead (#)	Pkg. Type
ISL28130	1	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	5	SC70, SOT23
ISL28133	1	1.8	5.5	0.008	300	0.4	0.1	65	0.018	17	-40	125	5	SC70, SOT23
ISL28230	2	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	8	DFN, MSOP, SOICN
ISL28233	2	1.8	6	0.006	180	0.4	0.2	65	0.018	17	-40	125	8	DFN, MSOP, SOICN
ISL28430	4	1.8	5.5	0.04	250	0.4	0.1	65	0.02	15	-40	125	14	SOICN, TSSOP
ISL28433	4	1.8	5.5	0.008	300	0.4	0.1	65	0.018	17	-40	125	14	SOICN, TSSOP
READ2303G	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	105	8	MSOP, TSSOP
READ2351J	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	125	8	TSSOP
READ2353J	2	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	125	8	TSSOP
READ4303G	4	1.8	5.5	6	1	0.55	0.35	-	0.04	10	-40	105	14	TSSOP
ISL28113	1	1.8	5.5	4	2	2	1	55	0.09	16	-40	125	5	SC70, SOT23
ISL28213	2	1.8	5.5	5	3	2	1	55	0.13	22	-40	125	8	MSOP, SOICN, SOT23
ISL28413	4	1.8	5.5	4	2	2	1	55	0.09	16	-40	125	14	SOICN, TSSOP
ISL28134	1	2.25	6	0.0025	300	3.5	1	10	0.675	65	-40	125	5, 8	SOICN, SOT23
ISL28114	1	1.8	5.5	4	2	5	2.5	40	0.3	26	-40	125	5	SC70, SOT23
ISL28214	2	1.8	5.5	4	3	5	2.5	40	0.039	31	-40	125	8	MSOP, SOICN
ISL28414	4	1.8	5.5	4	2	5	2.5	40	0.3	26	-40	125	14	SOICN, TSSOP
READ2302G	2	2.5	5.5	6	1	6	8	-	0.82	20	-40	105	8	TSSOP
READ2304G	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	105	8	MSOP, TSSOP
READ2352J	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	125	8	TSSOP
READ2354J	2	2.5	5.5	6	1	6	8	-	0.75	20	-40	125	8	TSSOP
READ4304G	4	2.5	5.5	6	1	6	8	-	0.75	20	-40	105	14	TSSOP
ISL24021	1	4.5	19	15	10000	12	19	190	2.2	300	-40	85	8	TDFN

## IMPORTANT NOTICE AND DISCLAIMER

RENESAS ELECTRONICS CORPORATION AND ITS SUBSIDIARIES (“RENESAS”) PROVIDES TECHNICAL SPECIFICATIONS AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for developers skilled in the art designing with Renesas products. You are solely responsible for (1) selecting the appropriate products for your application, (2) designing, validating, and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. Renesas grants you permission to use these resources only for development of an application that uses Renesas products. Other reproduction or use of these resources is strictly prohibited. No license is granted to any other Renesas intellectual property or to any third party intellectual property. Renesas disclaims responsibility for, and you will fully indemnify Renesas and its representatives against, any claims, damages, costs, losses, or liabilities arising out of your use of these resources. Renesas' products are provided only subject to Renesas' Terms and Conditions of Sale or other applicable terms agreed to in writing. No use of any Renesas resources expands or otherwise alters any applicable warranties or warranty disclaimers for these products.

(Disclaimer Rev.1.0 Mar 2020)

### Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,  
Koto-ku, Tokyo 135-0061, Japan  
[www.renesas.com](http://www.renesas.com)

### Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:  
[www.renesas.com/contact/](http://www.renesas.com/contact/)

### Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.