

Signal Gain and Noise Gain of the Op-Amp

Overview

This application note describes the signal gain and noise gain of the op-amp. The noise generated inside the op-amp and the input offset voltage are affected by the noise gain. Please use it as an aid in designing.

Table of Contents

Overview	1
Table of Contents	2
1. Introduction	3
1.1. Feedback circuit	3
1.2. Noise Gain.....	5
2. Signal Gain and Noise Gain.....	7
3. Example of actual amplifier circuit	10
3.1. Non-inverting amplifier circuit.....	10
3.2. Inverting amplifier circuit	11
3.3. Frequency characteristic	12
4. Summary	14
5. Related Links	15
RESTRICTIONS ON PRODUCT USE	16

1. Introduction

When amplifying small signals from various sensors with an op-amp circuit, the amplifier circuit must be designed considering S/N ratio between the input signal and the noise of the op-amp so that the signal you want to amplify is not buried in the noise generated inside the op-amp. When amplifying a signal in the op-amp circuit, the input signal is amplified by the signal gain, but the noise, offset voltage, etc. generated by the op-amp are amplified by the noise gain.

This application note describes the signal gain and noise gain of the op amp that should be considered when designing the op amp amplifier circuit.

1.1. Feedback circuit

This section explains the generally feedback circuitry prior to considering the operational amplifier noise gain (NG). Figure 1. shows the principle of the feedback circuit.

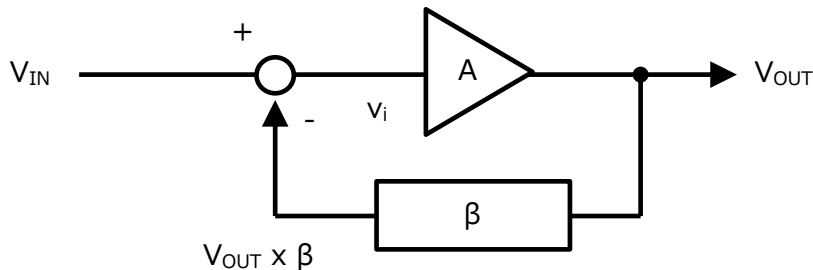


Figure 1. Feedback Circuit

Since the op-amp has a very high voltage gain, it is usually used as an amplifier circuit with feedback.

V_{OUT} ... Voltage-signal (Unit : V)

V_{IN} ... Input-voltage signal (unit : V)

A ... Open loop gain of the op-amp (Unit : times)

β ... Feedback ratio (Unit : times)

Now consider the transfer function of the above circuits.

In Figure 1,

$$v_i = V_{IN} - V_{OUT} \times \beta \dots (1)$$

$$V_{OUT} = A \times v_i \dots (2)$$

$$V_{OUT} = A (V_{IN} - V_{OUT} \times \beta) \dots (3)$$

Equation (4) can be obtained from these equations.

$$V_{OUT} / V_{IN} = A / (1 + A \times \beta) \dots (4)$$

Incidentally,

$1 + A \times \beta$... Feedback quantity

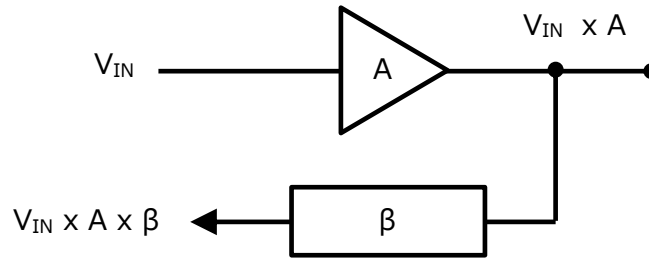


Figure 2. Loop Gain

Figure 2. shows an explanatory diagram of the loop gain. $A \times \beta$ is the feedback loop shown in Fig. 1, and represents the gain from the input V_{IN} to the output of the feedback β .

For this reason,

$$A \times \beta \cdots \text{Loop gain}$$

(4) Assuming that the open-loop gain A of the op-amp is very large as $A \gg 1$ in Equation, the gain G of the negative feedback circuit in Figure 1 can be approximated as $1/\beta$ as in Equation (5).

Assume that $V_{OUT}/V_{IN} = G$

$G \cdots$ Gain of the negative feedback circuit (Unit : times)

(4)From the equation

$$\begin{aligned} V_{OUT} / V_{IN} &= G \\ &= A / (1 + A \times \beta) \\ &= 1 / ((1 / A) + \beta) \\ &\doteq 1 / \beta \cdots (5) \end{aligned}$$

By configuring the negative feedback circuit, the feedback ratio, that is, the amplification factor of the circuit can be determined by the external resistor of the op-amp circuit, regardless of the value of the op-amp open-loop gain A . Also, the frequency band of the amplifier circuit that can be used can be widened (described in Section 3.3).

However, care must be taken because the amplification factor decreases and the circuit oscillates more easily due to feedback than when in an open loop where feedback is not applied.

1.2. Noise Gain

The noise gain (NG) is the voltage gain relative to the input referred noise of the op-amp. The input conversion noise is calculated by assuming that the noise generated by the op-amp itself is located at the input pin side. The op-amp noise is generated everywhere inside the op-amp circuit, but it is assumed that the op-amp non-inverting input terminal has a noise source (V_{NOISE}). This is amplified and included in the output voltage signal V_{OUT} , ($V_{OUT(Noise)}$ / V_{NOISE}) is called the noise gain. Note that noise includes voltage noise, current noise, and input offset voltage.

★ Signal gain of operational amplifier ...

$$\begin{aligned} & \text{Output voltage signal (input signal amplified) / Input voltage signal} \\ & = V_{OUT(\text{Signal})} / V_{IN(\text{Signal})} \end{aligned}$$

※The noise component (input conversion noise voltage, input offset voltage, etc.) generated inside the op-amp is used as the output signal does not include.

★ Noise gain of the operational amplifier ...

Output voltage signal (noise component) / noise generated from the inside of the operational amplifier

$$= V_{OUT(\text{Noise})} / V_{NOISE}$$

※The output signal is obtained by amplifying the noise component generated inside the op-amp. Noise (V_{NOISE}) generated from the inside of the op-amp is input-converted noise voltage, input-offset voltage, etc.

This noise gain can be expressed as $1/\beta$ in equation (5) above.

$$\begin{aligned} \text{Noise Gain (NG)} &= V_{OUT(\text{Noise})} / V_{NOISE} \\ &= 1 / \beta \quad \dots (6) \end{aligned}$$

In addition,

$$\text{Total output-voltage of the op-amp } V_{OUT} = V_{OUT(\text{Signal})} + V_{OUT(\text{Noise})} \quad \dots (7)$$

(The total noise component of the op amp, such as voltage noise, current noise, and offset voltage, can be expressed as the square root of the sum of these squares.)

Please refer to FAQ and application notes below for the noise of the op-amp described above.

■ FAQ: What types of noise affect an op-amp? 

[Click](#)

■ Application Note:

Low-Noise CMOS Operational Amplifier Ideal for Sensor Signal Amplification 

[Click](#)

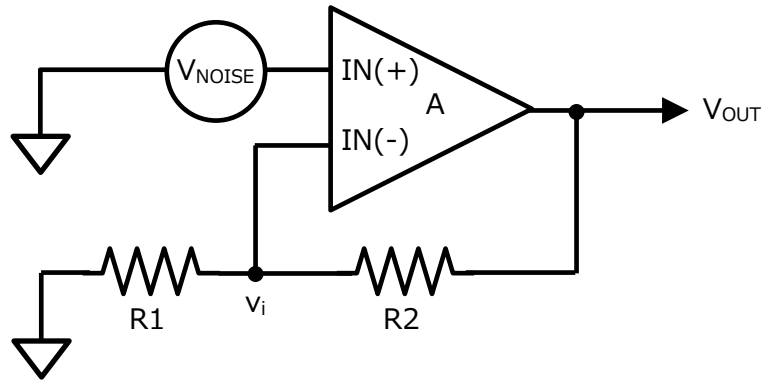


Figure 3. Illustration of Noise Gain

In Figure 3.,

$$V_{OUT} = A (V_{NOISE} - v_i) \cdots (8)$$

$$v_i = \beta \times V_{OUT} \cdots (9)$$

$$\text{Note that } \beta = R_1 / (R_1 + R_2) \cdots (10)$$

By substituting (9) into (8),

$$V_{OUT} = A (V_{NOISE} - \beta \times V_{OUT}) \rightarrow (1 + A \times \beta) \times V_{OUT} = A \times V_{NOISE} \cdots (11)$$

The Noise Gain NG indicates the ratio of the Noise Voltage V_{NOISE} to V_{OUT} .

For this reason,

$$V_{OUT} / V_{NOISE} = A / (1 + A \times \beta) = 1 / (1 / A + \beta) \cdots (12)$$

Where $A \gg 1$, or $1/A \ll \beta$, Equation (12) is as follows.

$$V_{OUT} / V_{NOISE} \cong 1 / \beta \cdots (13)$$

That is, the same result as in equation (5) is obtained and can be expressed as the noise gain

$$NG = 1 / \beta.$$

2. Signal Gain and Noise Gain

So far, we have explained that the feedback circuit, the negative feedback circuit, and the noise gain, and that the noise gain N_G can be shown as $N_G = 1/\beta$, assuming that the feedback ratio of the feedback circuit is β . This chapter describes the noise gain and signal gain concepts of the op-amp inverting and non-inverting circuits.

• **Non-inverting amplifier circuit**

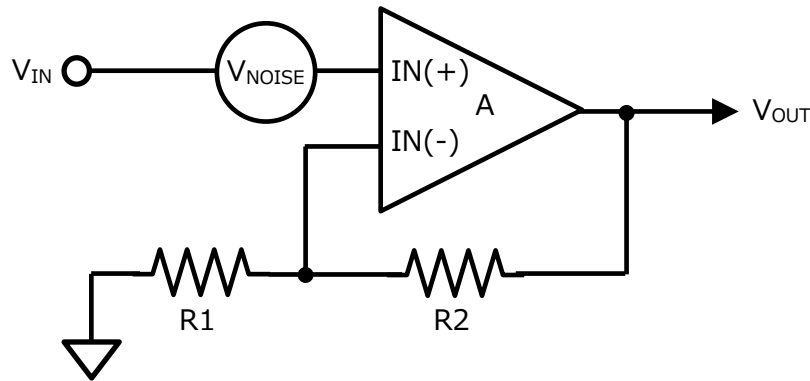


Figure 4. Non-inverting amplifier circuit

Figure 4. shows an example of a non-inverting amplifier circuit.

Signal Gain:

$$V_{OUT} = (1 + R_2/R_1) \times V_{IN} \cdots (14)$$

Therefore, $V_{OUT}/V_{IN} = 1 + R_2/R_1 \cdots$ Signal Gain

Noise Gain:

$$V_{OUT} = (1 + R_2/R_1) \times V_{NOISE} \cdots (15)$$

Therefore, $V_{OUT}/V_{NOISE} = 1 + R_2/R_1 \cdots$ Noise Gain

It can be expressed as. In other words, the noise gain N_G has the same amplification factor as the signal gain. This is because the noise component generated inside the op-amp can be modeled as having the non-inverting input pin side of the op-amp.

In Figure 4, the feedback ratio can be expressed as follows:

$$\text{Feedback ratio } \beta = R_1 / (R_1 + R_2) \cdots (16)$$

From equation (16)

$$1 / \beta = (R_1 + R_2) / R_1 = 1 + (R_2 / R_1) \cdots (17)$$

It can be expressed as.

• Inverting amplifier circuit

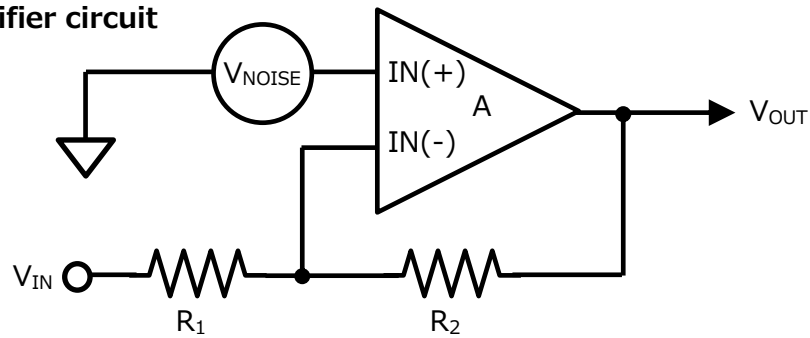


Figure 5. Inverting Amplifier Circuit

Figure 5. shows an example of an inverting amplifier circuit.

Signal Gain:

$$V_{OUT} = - (R_2/R_1) \times V_{IN} \cdots (18)$$

Thus, $V_{OUT}/V_{IN} = - (R_2/R_1) \cdots$ Signal Gain

Noise Gain:

$$V_{OUT} = (1 + R_2/R_1) \times V_{NOISE} \cdots (19)$$

Therefore, $V_{OUT} / V_{NOISE} = 1 + R_2/R_1 \cdots$ Noise Gain

It can be indicated. Even in the inverting amplifier circuit, the input conversion noise is modeled as having a non-inverting input pin. Since the signal enters from the inverting input terminal, the noise gain NG has an amplification factor that differs from the signal gain.

Conversely, the noise gain of the inverting amplifier circuit can be said to be the same as that of the non-inverting amplifier circuit.

The content described up to this point is summarized.

Table 1 summarizes the items described in circuit diagrams 4 and 5.

Table 1. Inverting amplifier circuit and non-inverting amplifier circuit

Item	Inverting amplifier circuit	Non-inverting amplifier circuit
Signal Gain	$-(R_2/R_1)$	$1 / \beta$ $(1 + R_2/R_1)$
Noise Gain	$1 / \beta$	$1 / \beta$
Loop Gain	$A \times \beta$	$A \times \beta$
Feedback quantity	$1 + A \times \beta$	$1 + A \times \beta$

The points in this chapter are summarized as follows.

- **The noise source generated inside the op-amp can be considered to be on the non-inverting input terminal IN (+) side of the op-amp.**
- **Assuming that the operational amplifier circuit is a feedback circuit and the feedback ratio is β , $1/\beta$ is the noise gain.**
- **In a non-inverting amplifier circuit, the signal gain is equal to the noise gain.**
- **In the inverting amplifier circuit, the signal gain and the noise gain are different.**
- **The input offset voltage of the op-amp and the noise voltage component inside the op-amp are amplified by the noise gain.**
- **Though the larger the noise gain is less likely to oscillate, the noise and the input offset voltage are also amplified by the noise gain and become larger.**
- **Frequency characteristics can also be considered in terms of noise gain (described later).**

3. Example of actual amplifier circuit

The following shows an example of operation when an op-amp with an input-offset voltage of approximately 1.4mV is amplified by an inverting amplifier circuit or a non-inverting amplifier circuit.

Sample Used : TOSHIBA CMOS Op Amp TC75S51F

Circuit supply voltage : $V_{DD} = 2.5\text{ V}$, $V_{SS} = -2.5\text{ V}$ operation

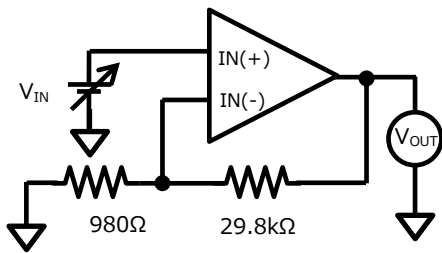
Input offset voltage V_{IO} : Approximately 1.4 mV sample

3.1. Non-inverting amplifier circuit

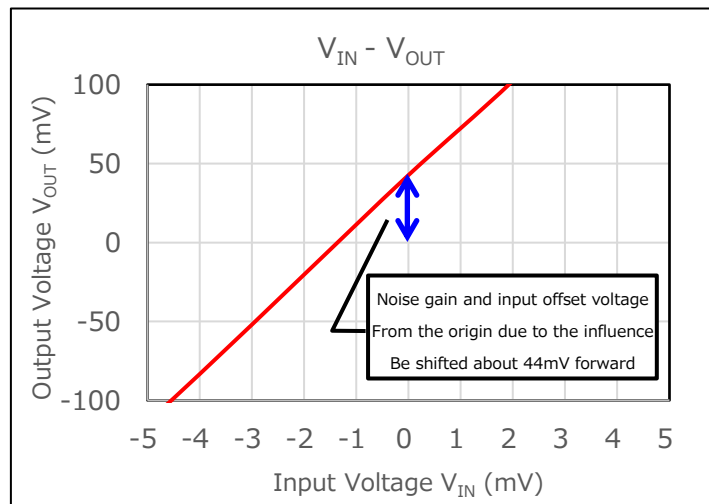
The following shows an example of operation in a non-inverting amplifier ($R_1:980\ \Omega$, $R_2:29.8\ \text{k}\Omega$).

Signal Gain $\cdots 1 + R_2/R_1 = 31.4$ times (30 dB)

Noise gain $\cdots 1 + R_2/R_1 = 31.4$ times (30 dB)



(a) Circuit diagram for the measurement



(b) Input-Output Voltage Waveform

Figure 6. Circuit Diagram and Input-Output Voltage Waveform of Non-inverting Amplifier Circuit

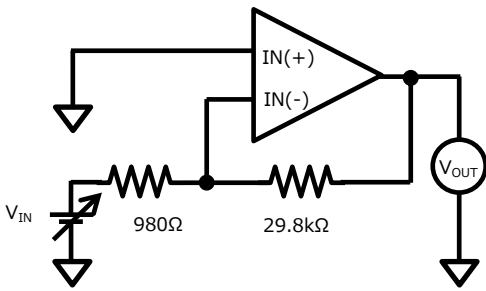
In this example, the amplifier is operated with a non-inverting amplifier whose gain is 31.4 times (30dB) (Figure 6.(a)). The circuitry consists of a sample with an input-offset-voltage V_{IO} of approximately 1.4mV. Figure 6.(b) shows the input-output voltage waveform. Since the input voltage is 31.4times, the output voltage is ideally $V_{OUT}=0\text{V}$ at the origin of $V_{IN}=0\text{V}$, but here, it can be seen that the input offset voltage 1.4mV is affected by the noise gain and $1.4\text{mV} \times (1 + 29.8\text{k}\Omega/980\Omega) \approx 44\text{mV}$ output voltage V_{OUT} is shifted to the positive direction.

3.2. Inverting amplifier circuit

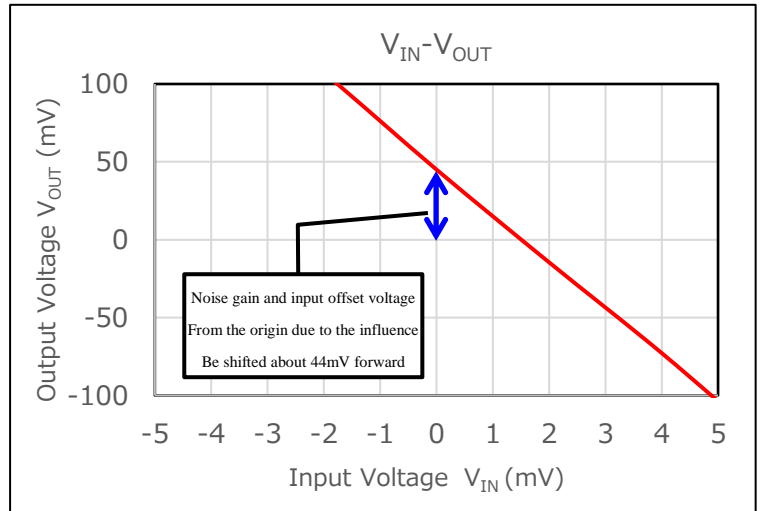
The following shows an example of operation in an inverting amplifier (R1:980Ω, R2:29.8kΩ).

Signal Gain ... $-R_2/R_1 = -30.4$ times (30dB)

Noise gain ... $1 + R_2/R_1 = 31.4$ times (30dB)



(a) Circuit diagram for the measurement



(b) Input-Output Voltage Waveform

Figure 7. Inverting Amplifier Circuit Diagram and Input-Output Voltage Waveform

In this example, the amplifier is operated with an inverting amplifier whose gain is -30.4 times (30dB) (Figure 7.(a)). The circuitry consists of a sample with an input-offset-voltage V_{IO} of approximately 1.4mV . Figure 7.(b) shows the input-output voltage waveform. Since the input voltage is multiplied by -30.4 , the output voltage is ideally $V_{OUT}=0\text{V}$ at the origin of $V_{IN}=0\text{V}$, but here, it can be seen that the input offset voltage 1.4mV is affected by the noise gain and $1.4\text{mV} \times (1 + 29.8\text{k}\Omega/980\Omega) \approx 44\text{mV}$ output voltage V_{OUT} is shifted to the positive direction.

3.3. Frequency characteristic

This section shows the frequency-response of a circuit in which the open-loop gain A and the closed-loop gain G are configured as 30dB in our CMOS op-amp TC75S51F.

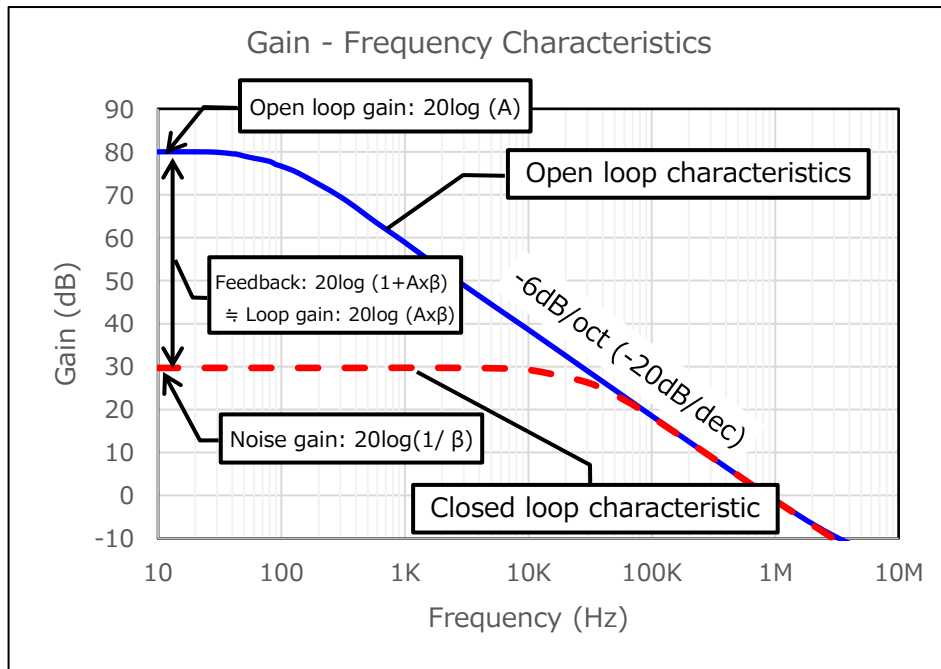


Figure 8. Frequency response (TC75S51F, Supply voltage $V_{DD}=2.5V$, $V_{SS}=-2.5V$)

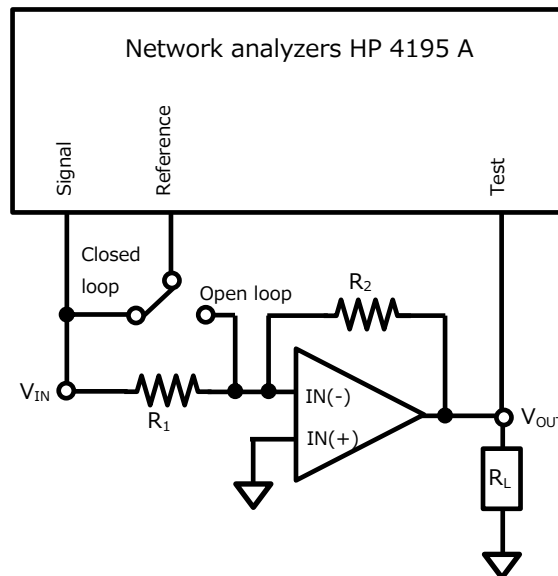


Figure 9. Gain Frequency Characteristics Measurement Circuit

Figure 8. shows the gain vs frequency response of TC75S51F (measuring circuit: Figure 9.). With respect to the open-loop characteristics, the frequency characteristics of the circuit composed of the closed-loop gain 30dB show that the frequency band that can be used with the set gain 30dB is as wide as approximately 10kHz (note that the amplification factor of the op-amp circuit has the

frequency characteristics). The closed loop gain is the same as the noise gain ($1/\beta$).

If $Ax\beta \gg 1$, then the feedback $20\log(1+Ax\beta)$ and the loop gain $20\log(Ax\beta)$ can be approximated to be nearly equal.

4. Summary

This application note describes the signal gain and noise gain of the op-amp. The noise and offset voltage of the op-amp are amplified by the noise gain and output from the op-amp. The noise gain can be expressed as $1/\beta$ using the feedback ratio β of the feedback circuit. This $1/\beta$ is related to the frequency characteristics and gain of the op-amp, and also related to the loop gain.

It is important to select a product with a small offset voltage or a product with a small noise voltage when selecting an op-amp in the circuit design. However, it is also necessary to consider the required S/N ratio and frequency band by using the concept of signal gain and noise gain described in this application.

5. Related Links

■ Product Line Ups (Catalog)



Click

■ Product Line Ups (Detail)



Click

■ Product Stock & Purchase



■ FAQ of Op-Amps or Comparator



Click

■ Application Notes



Click

RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA". Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**