Gain Block Analysis for the THS3001

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Gain Block Analysis for the THS3001

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ABSTRACT

This report describes how to construct a gain block diagram for a current feedback op amp and relates the diagram to stability and gain analysis using parameters of the THS3001 op amp.

1 Introduction

The application report *Voltage Feedback vs Current Feedback Op Amps,* SLVA051, outlines the operation of a current feedback op amp in relation to a voltage feedback op amp. The basic difference between a current feedback op amp and a voltage feedback op amp is that its transfer function is a transimpedance equal to the output voltage divided by the input current at the negative input, i.e., $Zt = \frac{Vo}{Ie}$.

When constructing a gain block diagram, this basic difference in operation changes the mathematical functions represented by the gain blocks. By using the same methods that are used to construct a gain block diagram for a voltage feedback op amp, a gain block diagram can also be constructed for a current feedback op amp. Once constructed, the gain block diagram can be manipulated using standard techniques.

2 Gain Block Diagram Basics

Figure 1 shows a basic current feedback op amp model configured as a noninverting amplifier by using feedback resistor *R2* and gain setting resistor *R1*.

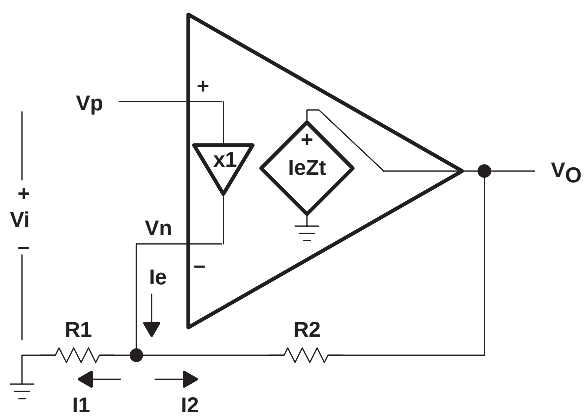

Figure 1. Noninverting Amplifier Using Current Feedback Model

Referring to Figure 1:

By observation, *Vo = IeZt* and *Vn = Vp = Vi*. Summing the currents at node *Vn: Ie = I1 + I2.* Substituting and rearranging:

$$Ie = Vi\left(\frac{1}{R1} + \frac{1}{R2}\right) - Vo\left(\frac{1}{R2}\right) = (Vi \times c) - (Vo \times b) \;\; where \;\; c = \left(\frac{1}{R1} + \frac{1}{R2}\right) \text{ and}$$

$b = \left(\frac{1}{R2}\right)$. Using these mathematical relationships, the block diagram shown in Figure 2 is constructed. Refer to Appendix A for the gain block diagram for an inverting amplifier.

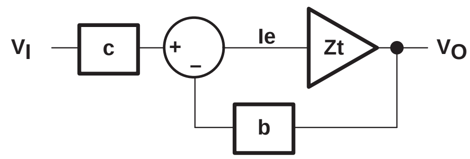

Figure 2. Block Diagram

2.1 Gain Analysis

Using the block diagram, the transfer function for the amplifier circuit is computed by:

$$\frac{Vo}{Vi} = \frac{c}{b}\left[\frac{1}{1 + \frac{1}{Zt \times b}}\right] \text{ substituting for c and b, } \frac{Vo}{Vi} = \left(1 + \frac{R1}{R2}\right)\left[\frac{1}{1 + \frac{R2}{Zt}}\right]$$

The above equation describes a transfer function where the gain is equal to $\frac{c}{b}$ as long as $Zt \times b >> 1$. The frequency at which $|Zt \times b| = 1$ determines the bandwidth.

2.2 Stability Analysis

The loop transmission, $T = Zt \times b$, is used for stability analysis. $\angle T$ at the frequency where $|T| = 1$ determines the stability of the circuit.

Normally it is desired to have $\angle T \leq -115°$ when $|T| = 1$.

3 Application to THS3001

Figure 3 is a plot of the THS3001’s open loop transimpedance magnitude and phase vs frequency. The magnitude plot is in dB ohms[1]. Assuming a purely resistive feedback network, plotting a horizontal line that intersects $|Zt|$ where the $\angle Zt$ is approximately –115°, determines the value of $\frac{1}{b}$ required for a phase margin of 65°. Doing this results in $\frac{1}{b} \approx 60\ dB\ ohms$. Using $b = \frac{1}{R2}$ and converting to ohms, results in the minimum value of R2 = 1 kΩ for a phase margin of 65°. R2 = 1 kΩ is the value recommended in the data sheet for the feedback resistor when using the THS3001 as a unity gain amplifier. Values greater than 1 kΩ reduce the bandwidth and increase stability. Reference the THS3001 data sheet, literature number SLOS217.

[1] $dB\ ohms = 20 log_{10}\left(\frac{V}{1} \times \frac{1}{1\Omega}\right)$

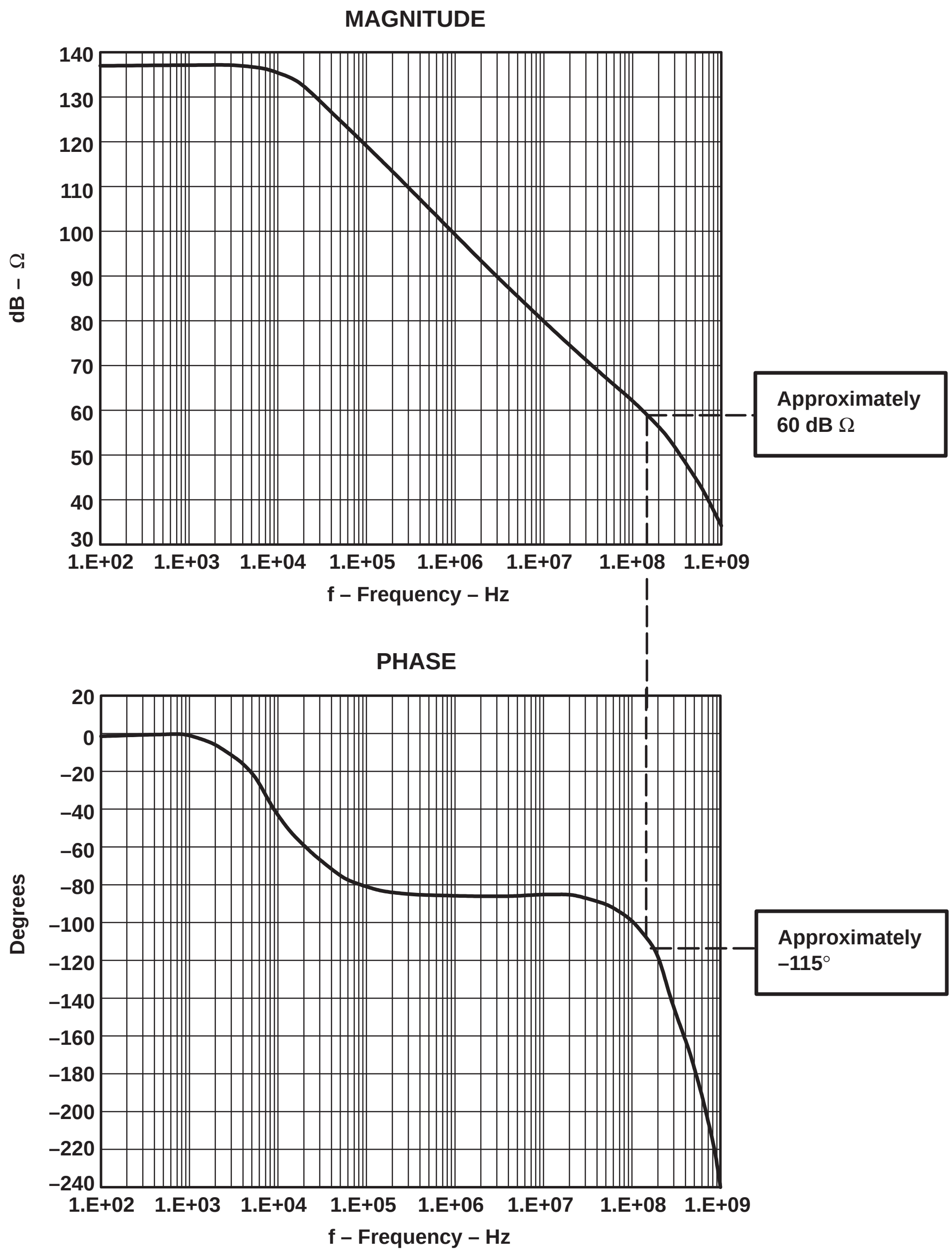

Figure 3. THS3001 Open Loop Transimpedance

Using feedback components that reduce the impedance or that cause additional phase shift in the feedback path will erode the phase margin, and possibly lead to unstable operation. This is why using capacitance in the feedback path is not recommended and why parasitic capacitance at the negative input must be minimized when using the THS3001.

In the discussion above it is assumed that the widest possible bandwidth is desired. This may not be the case. The resistance of R2 can be chosen to set the bandwidth to whatever is desired. Simply convert |*Zt*| (in dB ohms) at the bandwidth desired into ohms, and use this value for R2.

Example: set bandwidth to 10 MHz.

Solution: $|Zt|$ =80 dB ohms at 10 MHz, therefore $R2 = 10^{\left(\frac{80}{20}\right)} \times \frac{1\Omega}{1} = 10\,k\Omega$.

As would be expected, variations in *Zt*, second order effects due to the finite output and input impedances that are not included here, and parasitic elements are more influential at higher frequencies. All these things combine so that the above calculation serves as a good approximation or starting point, but the intended circuit needs to be built and tested to confirm the desired frequency response given a specific configuration.

4 Summary

Gain block diagrams are widely used to simplify gain and stability analysis in voltage feedback op amp circuits. By analyzing the circuit so that the mathematical relationships between the nodes are found, the gain block diagram is constructed for a current feedback op amp. With the gain block diagram in place, the wealth of information available on manipulating such diagrams can be tapped and used to advantage without regard to the source circuit.

The gain block diagram developed here and the transfer function data provides the basic tools for gain and stability analysis of circuits using the THS3001.

Appendix A shows how to develop a gain block diagram for an inverting current feedback amplifier. The techniques can be applied to other circuits as well to develop the required diagram for analysis.

Appendix A Gain Block Diagram for Inverting Current Feedback Amplifier

A.1 Introduction

Figure A–1 (a) shows the circuit model for an inverting current feedback amplifier. By observation, $Vo = IeZt$ and $Vn = Vp = 0$. Summing the currents at Vn: $Ie = I1 + I2$. Substituting and rearranging:

$Ie = -Vi\left(\frac{1}{R1}\right) - Vo\left(\frac{1}{R2}\right) = (Vi \times c) - (Vo \times b)$ where $c = -\left(\frac{1}{R1}\right)$ and $b = -\left(\frac{1}{R2}\right)$.

Using these relationships, the block diagram shown in Figure A–1 (b) can be drawn.

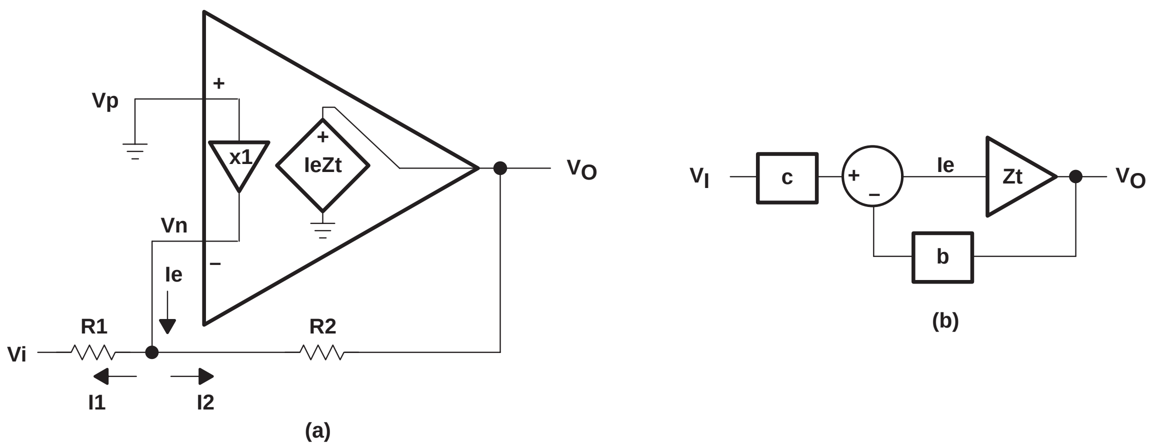

Figure A–1. (a) Inverting Current Feedback Amplifier, (b) Gain Block Diagram

A.2 Gain Analysis

Using the block diagram, the transfer function for the amplifier circuit is computed by: $\frac{Vo}{Vi} = \frac{c}{b}\left[\frac{1}{1 + \frac{1}{Zt \times b}}\right]$ substituting for c and b, $\frac{Vo}{Vi} = -\left(\frac{R1}{R2}\right)\left[\frac{1}{1 + \frac{R2}{Zt}}\right]$

This equation describes a transfer function where the gain is equal to $\frac{c}{b}$ as long as $Zt \times b >> 1$. The frequency at which $|Zt \times b| = 1$ determines the bandwidth.

A.3 Stability Analysis

The loop transmission, $T = Zt \times b$, is used for stability analysis. $\angle T$ at the frequency where $|T| = 1$ determines the stability of the circuit. As $\angle T$ approaches –180° when $|T| = 1$, the circuit becomes unstable.