Lecture (1)
Properties of Negative Feedback
(Theoretical)

Some Properties of Negative Feedback

1. Gain Desensitivity:

$$A_f = \frac{A}{1+A\beta} \longrightarrow \frac{dA_f}{dA} = \frac{1}{(1+A\beta)^2} \longrightarrow dA_f = \frac{dA}{(1+A\beta)^2}$$

Then, $\frac{dA_f}{A_f} = \frac{dA}{(1+A\beta)^2} \times \frac{1+A\beta}{A} = \frac{1}{1+A\beta}\frac{dA}{A} \longrightarrow \frac{dA_f}{A_f} = \frac{1}{1+A\beta}\frac{dA}{A}$

Gain Sensitivity (S)

$$S = \frac{dA_f/A_f}{dA/A} = \frac{1}{1+A\beta}$$

Gain Desensitivity (D)

$$D = 1/S = 1 + A\beta$$

The percentage change in A_f (due to variations in some circuit parameter) is smaller than the percentage change in A by a factor equal to the amount of feedback. For this reason, the amount of feedback, $1 + A\beta$, is also known as the desensitivity factor.

2. Bandwidth Extension:

Consider an amplifier whose high-frequency response is characterized by a single pole. Its gain at mid and high frequencies can be expressed as

$$A(s) = \frac{A_M}{1 + s/\omega_H} \tag{10.10}$$

where A_M denotes the midband gain and ω_H is the upper 3-dB frequency. Application of negative feedback, with a frequency-independent factor β, around this amplifier results in a closed-loop gain $A_f(s)$ given by

$$A_f(s) = \frac{A(s)}{1 + \beta A(s)}$$

Substituting for $A(s)$ from Eq. (10.10) results, after a little manipulation, in

$$A_f(s) = \frac{A_M/(1 + A_M\beta)}{1 + s/\omega_H(1 + A_M\beta)} \tag{10.11}$$

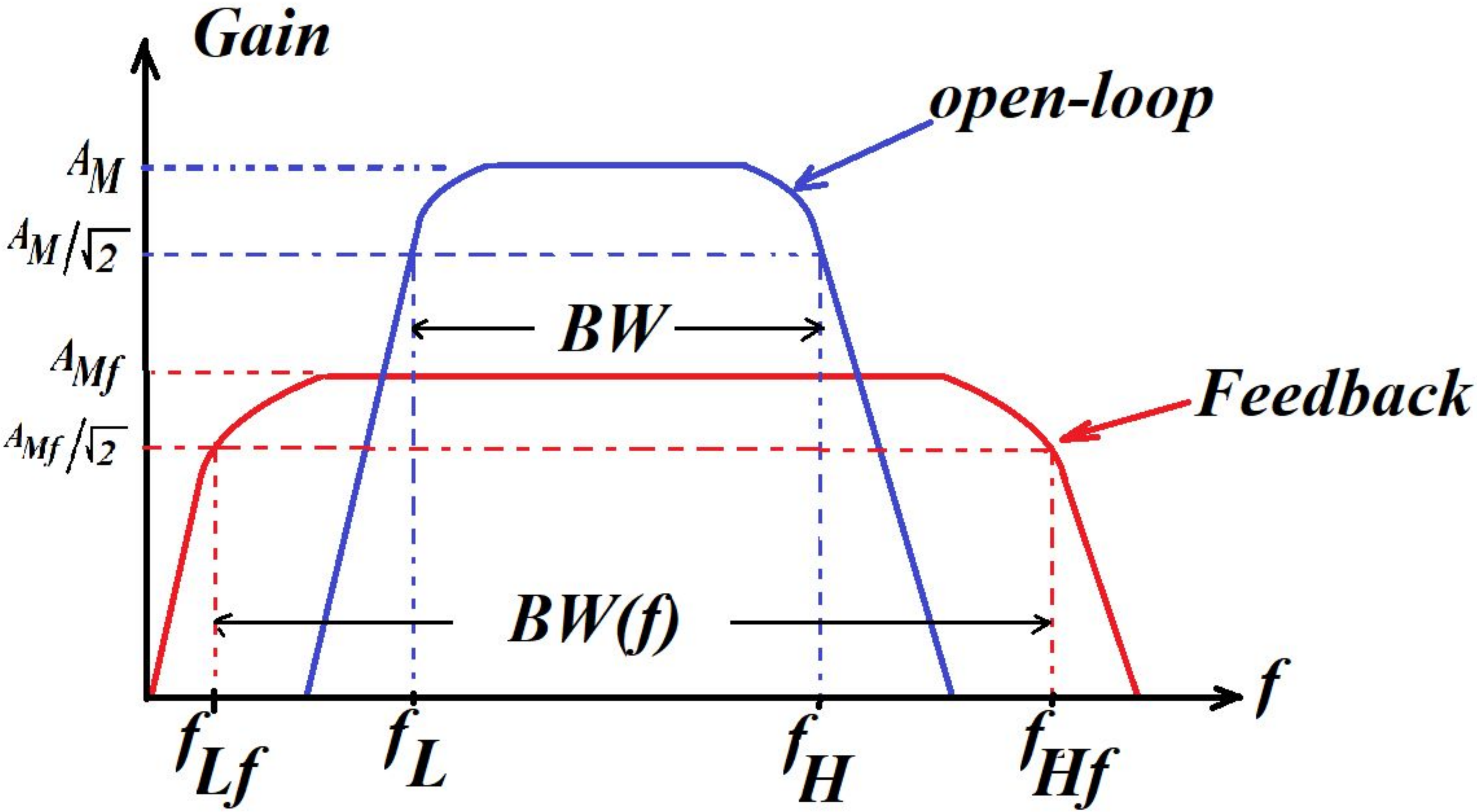
Thus the feedback amplifier will have a midband gain of $A_M/(1 + A_M\beta)$ and an upper 3-dB frequency ω_{Hf} given by

$$\omega_{Hf} = \omega_H(1 + A_M\beta) \tag{10.12}$$

It follows that the upper 3-dB frequency is increased by a factor equal to the amount of feedback.

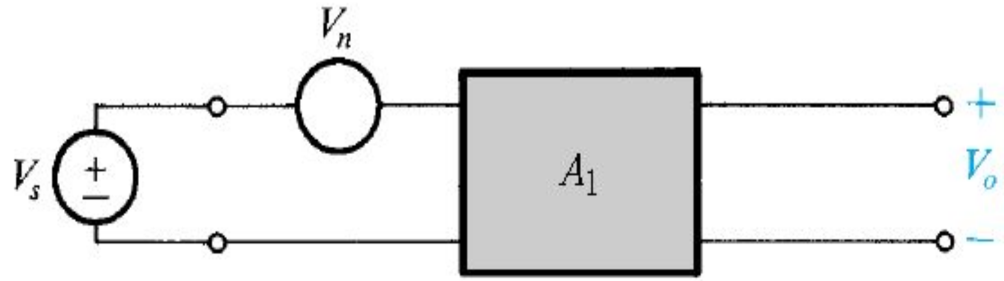
Similarly, it can be shown that if the open-loop gain is characterized by a dominant low-frequency pole giving rise to a lower 3-dB frequency ω_L, then the feedback amplifier will have a lower 3-dB frequency ω_{Lf},

$$\omega_{Lf} = \frac{\omega_L}{1 + A_M\beta} \tag{10.13}$$



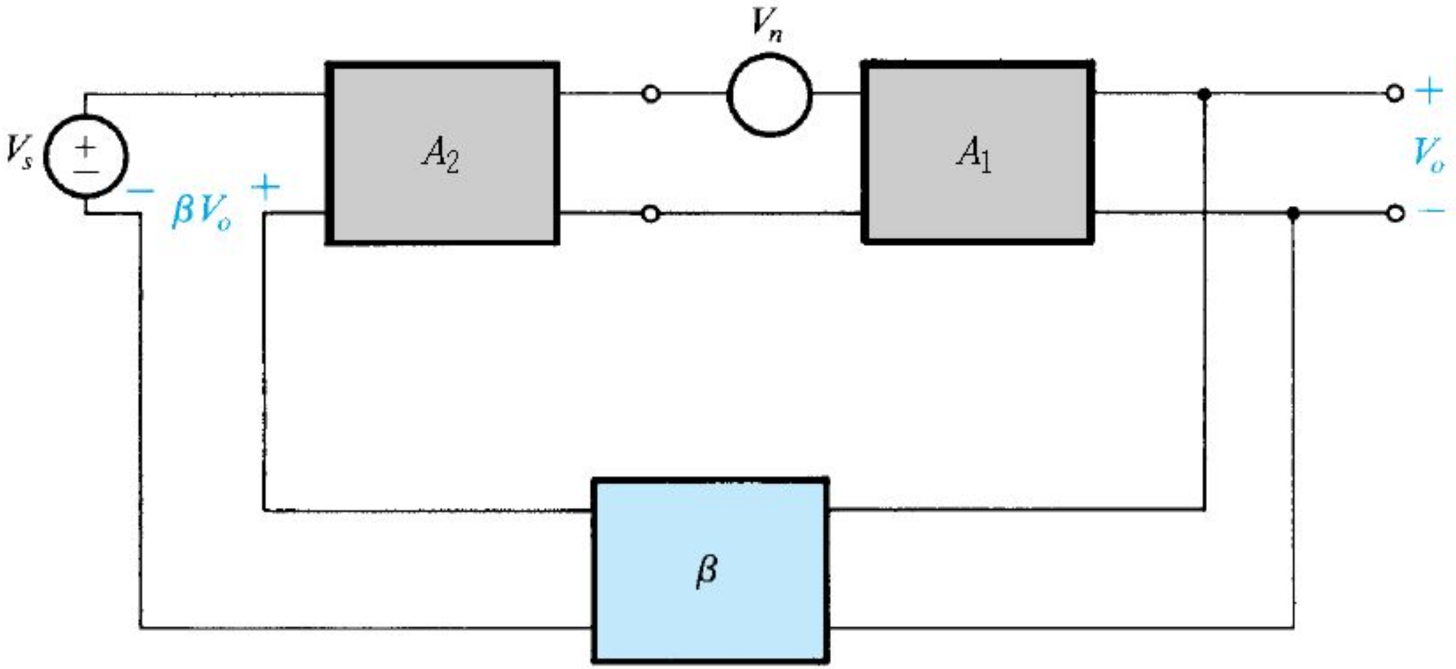
Gain
open-loop
A_M
$A_M/\sqrt{2}$
BW
A_{Mf}
Feedback
$A_{Mf}/\sqrt{2}$
BW(f)
f
f_{Lf}
f_L
f_H
f_{Hf}

3. Reduce the effect of noise (Increase S/N ratio):



Open loop amplifier

S/N or S/I = Vs/Vn



Closed- loop (feedback) amplifier

$$V_o = V_s \frac{A_1 A_2}{1 + A_1 A_2 \beta} + V_n \frac{A_1}{1 + A_1 A_2 \beta}$$

The signal-to-interference ratio

$$\frac{S}{I} = \frac{V_s}{V_n} A_2$$

4. Reduction in Nonlinear Distortion:

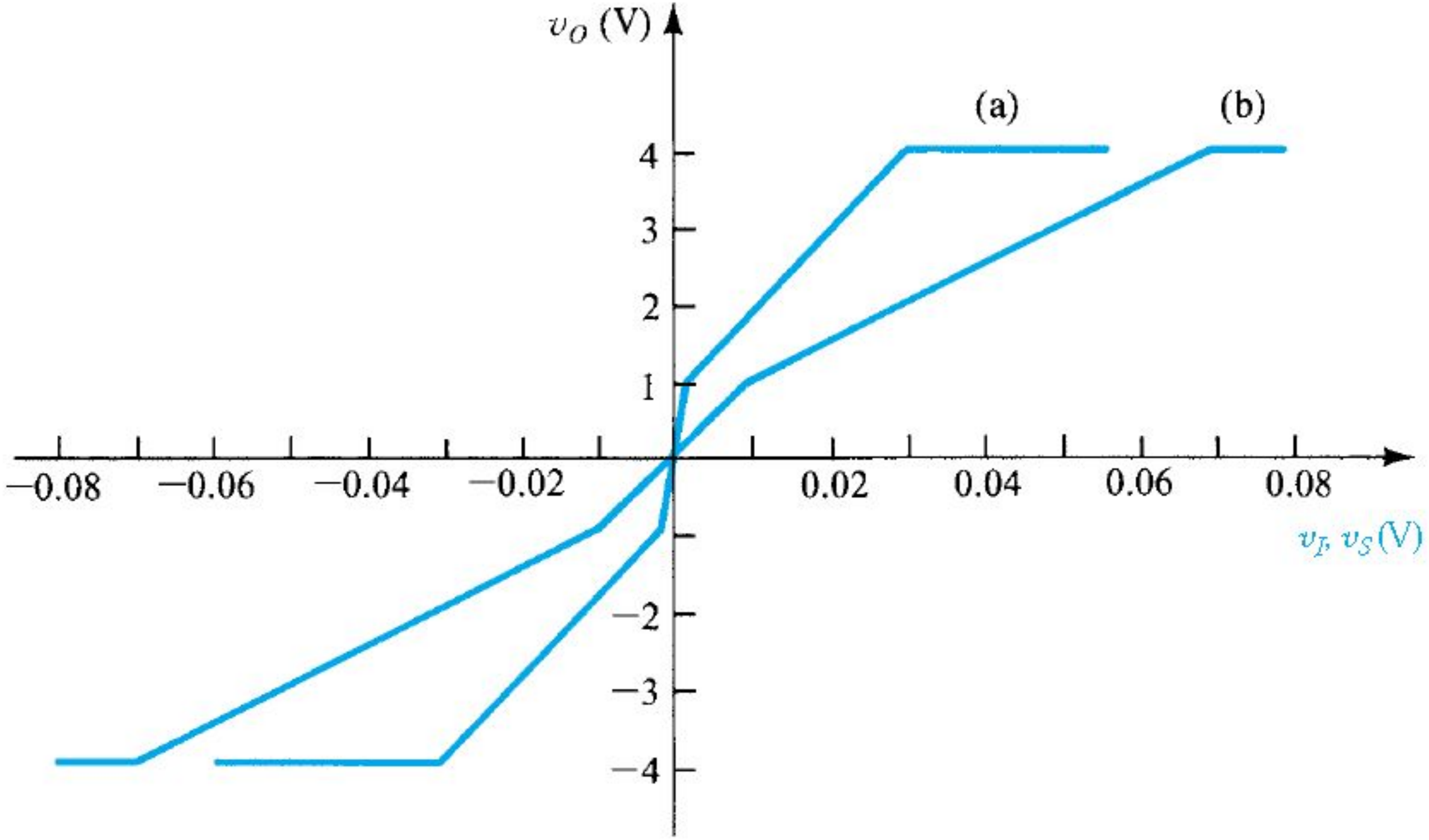


Figure 10.5 Illustrating the application of negative feedback to reduce the nonlinear distortion in amplifiers. Curve (a) shows the amplifier transfer characteristic (v_O versus v_I) without feedback. Curve (b) shows the characteristic (v_O versus v_S) with negative feedback ($\beta = 0.01$) applied.

Curve (a) in Fig. 10.5 shows the transfer characteristic v_O versus v_I of an amplifier. As indicated, the characteristic is piecewise linear, with the voltage gain changing from 1000 to 100 and then to 0. This nonlinear transfer characteristic will result in this amplifier generating a large amount of nonlinear distortion.

The amplifier transfer characteristic can be considerably **linearized** (i.e., made less nonlinear) through the application of negative feedback. That this is possible should not be too surprising, since we have already seen that negative feedback reduces the dependence of the overall closed-loop amplifier gain on the open-loop gain of the basic amplifier. Thus large changes in open-loop gain (1000 to 100 in this case) give rise to much smaller corresponding changes in the closed-loop gain.

To illustrate, let us apply negative feedback with $\beta = 0.01$ to the amplifier whose open-loop voltage transfer characteristic is depicted in Fig. 10.5. The resulting transfer characteristic of the closed-loop amplifier, v_O versus v_S, is shown in Fig. 10.5 as curve (b). Here the slope of the steepest segment is given by

$$A_{f1} = \frac{1000}{1 + 1000 \times 0.01} = 90.9$$

and the slope of the next segment is given by

$$A_{f2} = \frac{100}{1 + 100 \times 0.01} = 50$$

Thus the order-of-magnitude change in slope has been considerably reduced. The price paid, of course, is a reduction in voltage gain. Thus if the overall gain has to be restored, a preamplifier should be added. This preamplifier should not present a severe nonlinear-distortion problem, since it will be dealing with smaller signals.

Table 10.1 Summary of Relationships for the Four Feedback-Amplifier Topologies

Feedback Amplifier	Feedback Topology	x_i	x_o	x_f	x_s	A	β	A_f	Source Form	Loading of Feedback Network is Obtained: At Input	Loading of Feedback Network is Obtained: At Output	To Find β, Apply to Port 2 of Feedback Network	R_{if}	R_{of}
Voltage	Series–shunt	V_i	V_o	V_f	V_s	$\frac{V_o}{V_i}$	$\frac{V_f}{V_o}$	$\frac{V_o}{V_s}$	Thévenin	By short-circuiting port 2 of feedback network	By open-circuiting port 1 of feedback network	a voltage, and find the open-circuit voltage at port 1	$R_i(1+A\beta)$	$\frac{R_o}{1+A\beta}$
Current	Shunt–series	I_i	I_o	I_f	I_s	$\frac{I_o}{I_i}$	$\frac{I_f}{I_o}$	$\frac{I_o}{I_s}$	Norton	By open-circuiting port 2 of feedback network	By short-circuiting port 1 of feedback network	a current, and find the short-circuit current at port 1	$\frac{R_i}{1+A\beta}$	$R_o(1+A\beta)$
Transconductance	Series–series	V_i	I_o	V_f	V_s	$\frac{I_o}{V_i}$	$\frac{V_f}{I_o}$	$\frac{I_o}{V_s}$	Thévenin	By open-circuiting port 2 of feedback network	By open-circuiting port 1 of feedback network	a current, and find the open-circuit voltage at port 1	$R_i(1+A\beta)$	$R_o(1+A\beta)$
Transresistance	Shunt–shunt	I_i	V_o	I_f	I_s	$\frac{V_o}{I_i}$	$\frac{I_f}{V_o}$	$\frac{V_o}{I_s}$	Norton	By short-circuiting port 2 of feedback network	By short-circuiting port 1 of feedback network	a voltage, and find the short-circuit current at port 1	$\frac{R_i}{1+A\beta}$	$\frac{R_o}{1+A\beta}$