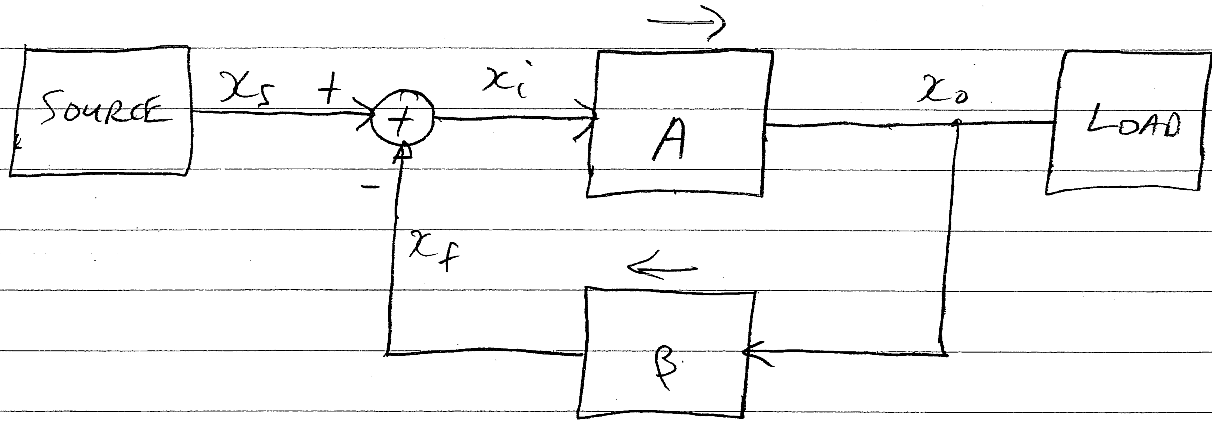
INTRODUCTION TO FEEDBACK

BASIC FEEDBACK STRUCTURE



x_s, x_f, x_i COULD BE VOLTAGES OR CURRENTS

x_o COULD BE VOLTAGE OR CURRENT

A => OPEN LOOP AMPLIFIER

$$x_o = A x_i \quad (1)$$

β => FEEDBACK FACTOR (USUALLY PASSIVE NETWORK)

$$x_f = \beta x_o \quad (2)$$

$$x_i = x_s - x_f \quad (3)$$

COMBINING ① ② + ③ GIVES

CLOSED-LOOP GAIN, A_f

$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta} \qquad (4)$$

WHERE <u>$A\beta$</u> IS CALLED THE

<u>**LOOP GAIN**</u> DEFINE $L \equiv A\beta$
(UNITS OF L DIMENSIONLESS)

AS $A \to \infty \Rightarrow A_f = \frac{1}{\beta}$

SO CLOSED LOOP IS DETERMINED BY PASSIVE NETWORK (WHICH CAN BE VERY ACCURATE)

ALSO CAN SHOW

$$x_i = \frac{1}{1 + A\beta} x_s$$

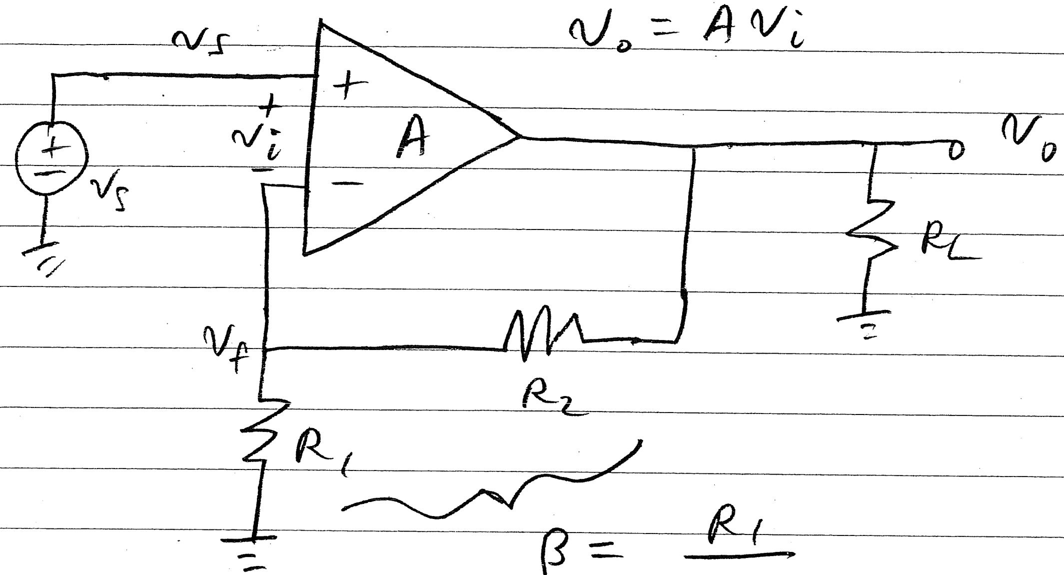
SO AS $A \to \infty \Rightarrow x_i \to 0$

IN OTHER WORDS $x_f \approx x_s$ AS $A \to \infty$

THE FEEDBACK SIGNAL, x_s, TRACKS x_s
& ERROR SIGNAL, x_i GOES TO ZERO

NON-INVERTING OPAMP EXAMPLE

$v_o = A v_i$



$$\beta = \frac{R_1}{R_1 + R_2}$$

$$A_f = \frac{A}{1 + A\beta}$$

IF $A\beta \gg 1 \Rightarrow A_f \approx \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$

Ex $R_2 = 9k \quad R_1 = 1k$

FIND A_f FOR 2 CASES

1) $A = 10^4$

2) $A = 0.8 \times 10^4$

(IF4)

1) $$A_f = \frac{10^4}{1+(10^4)(\frac{1}{10})}$$

$$= 9.99$$

2) $$A_f = \frac{0.8\times 10^4}{1+(0.8\times 10^4)(\frac{1}{10})} = 9.9875$$

SO A 20% DECREASE IN A RESULTS IN A 0.025% DECREASE IN A_f

USEFUL PROPERTIES OF NEGATIVE FEEDBACK

- GAIN DESENSITIVITY
- BANDWIDTH EXTENSION
- REDUCTION IN NON-LINEAR DISTORTION
- INPUT & OUTPUT IMPEDANCE ENHANCEMENT

GAIN DESENSITIVITY

USING (4) CAN SHOW (SEE NEXT PAGE)

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

DIVIDE BOTH SIDES BY (4)

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

SO A PERCENTAGE CHANGE IN A OF K_A %
RESULTS IN A PERCENTAGE CHANGE OF A_f
OF $K_{Af} = \frac{K_A}{(1+A\beta)}$

(4) $A_f = \frac{A}{1+A\beta}$ ASSUME β CONSTANT

$$\frac{d(A_f)}{dA} = \frac{d}{dA}\left(\frac{A}{1+A\beta}\right)$$

RECALL (QUOTIENT RULE) $\frac{d}{dx}\left(\frac{f(x)}{g(x)}\right) = \frac{f'(x)g(x) - f(x)g'(x)}{g^2(x)}$

HERE $f(A) = A \Rightarrow f'(A) = 1$

$g(A) = 1 + A\beta \Rightarrow g'(A) = \beta$

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

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

Ex IF A CAN CHANGE BY 10%
WHAT SIZE A IS REQUIRED
TO KEEP THE CHANGE IN A_f LESS
THAN 1% IF $A_f = 20$.
ALSO FIND β.

$$A_f = \frac{A}{1+A\beta} = 20$$

ALSO $$1\% = \frac{10\%}{1+A\beta} \Rightarrow 1+A\beta = 10$$

$$A = 20(1+A\beta) = \underline{\underline{200}}$$

$$1+A\beta = 10 \Rightarrow A\beta = 9$$

$$\beta = \frac{9}{A} = \frac{9}{200} = \underline{\underline{0.045}}$$

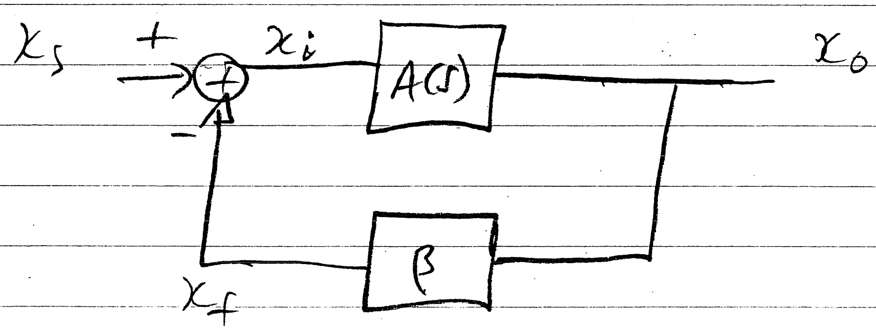
IF $A \to \infty \Rightarrow A_f = \frac{1}{\beta} = 22.2$ V/V

BANDWIDTH EXTENSION

AN AMPLIFIER WITH A SINGLE-POLE LOW PASS RESPONSE CAN BE WRITTEN AS

$$A(s) = \frac{A_M}{1 + s/\omega_H} \qquad (5)$$

IF THIS AMP IS USED IN FEEDBACK SYSTEM WITH FEEDBACK β



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

SUBSTITUTE IN (5)

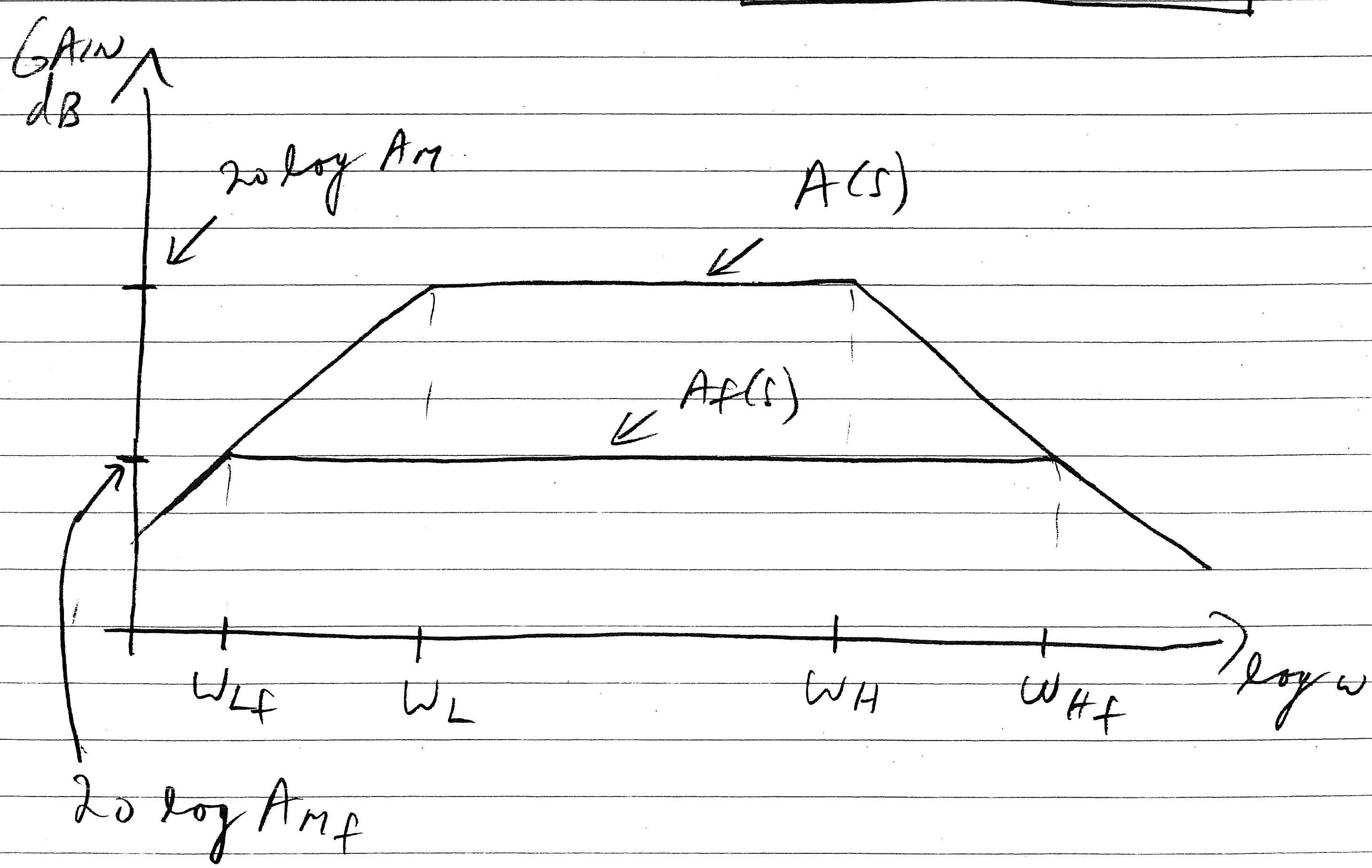
$$A_f(s) = \frac{A_M / (1 + A_M\beta)}{1 + s / [\omega_H (1 + A_M\beta)]}$$

SO MIDBAND GAIN CHANGED TO $A_{mf} = \frac{A_m}{(1+A_m\beta)}$

AND 3dB FREQ INCREASED TO $\boxed{\omega_{Hf} = \omega_H (1+A_m\beta)}$

CAN SHOW SIMILAR RESULT FOR

ω_L CHANGES TO $\boxed{\omega_{Lf} = \frac{\omega_L}{(1+A_m\beta)}}$

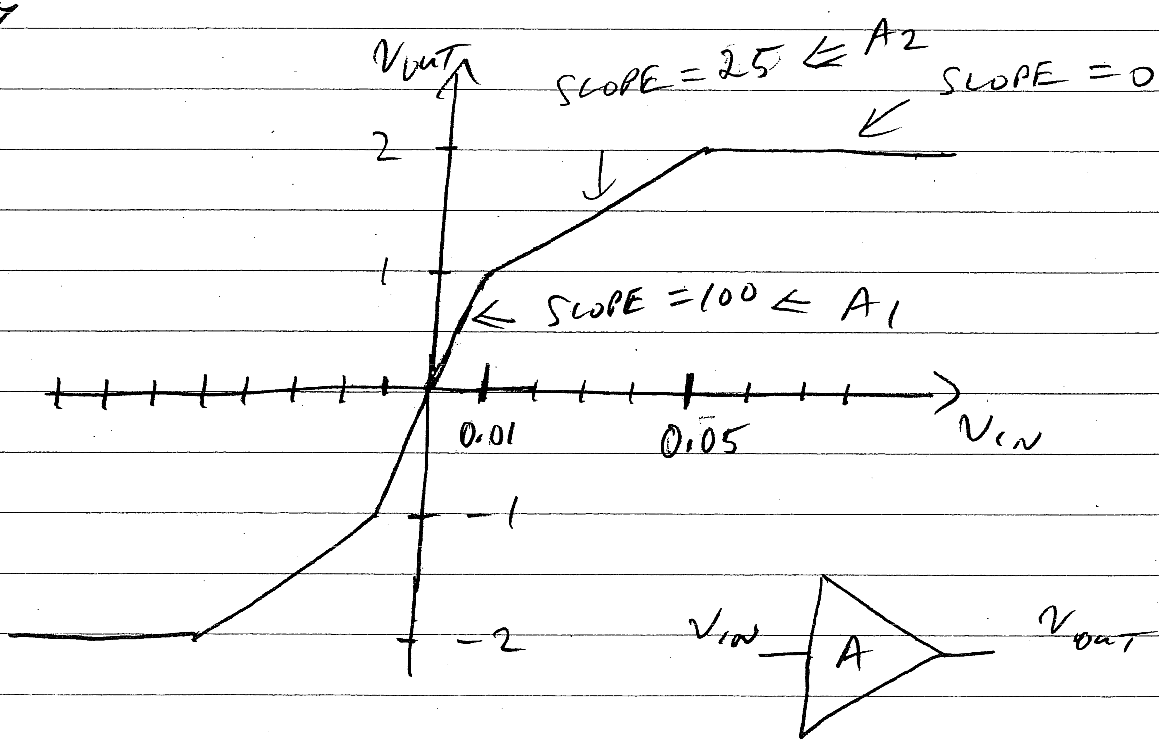


REDUCTION IN NON-LINEAR DISTORTION

- NON-LINEAR DISTORTION WILL OCCUR IN AMP IF GAIN CHANGES WITH INPUT LEVEL

- DISTORTION IS WORSE IF GAIN VARIATION IS WORSE

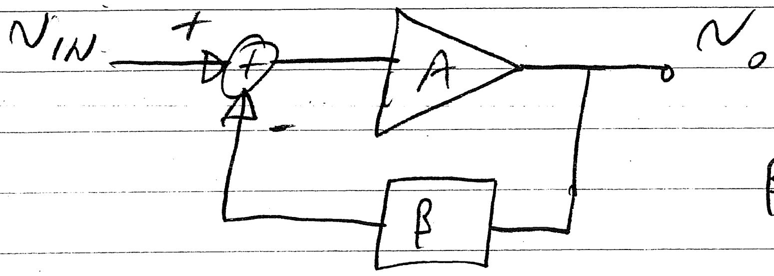
FOR EXAMPLE, CONSIDER AMP GAIN GIVEN BY



LARGE DISTORTION DUE TO GAIN CHANGING FROM 100 TO 25 AND THEN SATURATES WHEN $|V_o| > 2$ (CLIPPING)

IF10

PUT AMP IN FEEDBACK LOOP
WITH $\beta = 1$



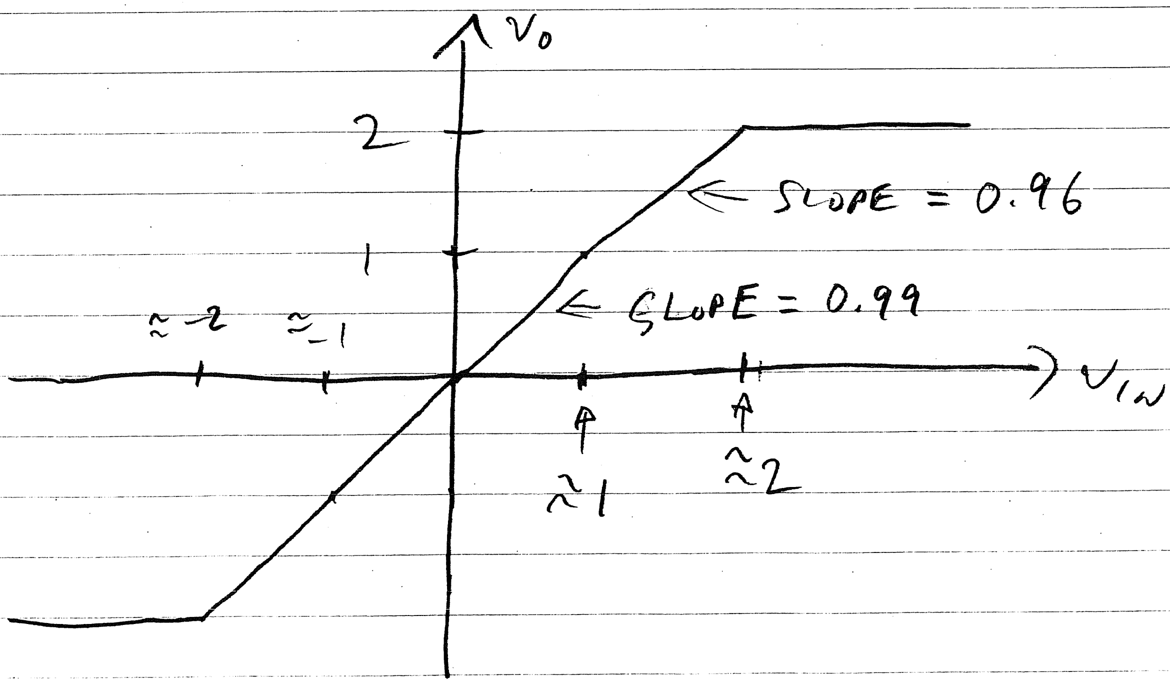
$\beta = 1$

WHEN A_1 GAIN $A_{f_1} = \frac{A_1}{1 + A_1\beta} = \frac{100}{1+100}$

$= 0.99\ V/V$

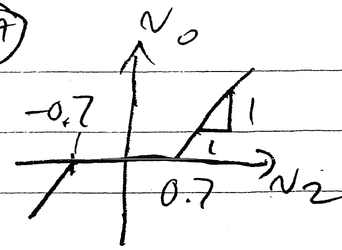
WHEN A_2 GAIN $A_{f_2} = \frac{A_2}{1 + A_2\beta} = \frac{25}{1+25}$

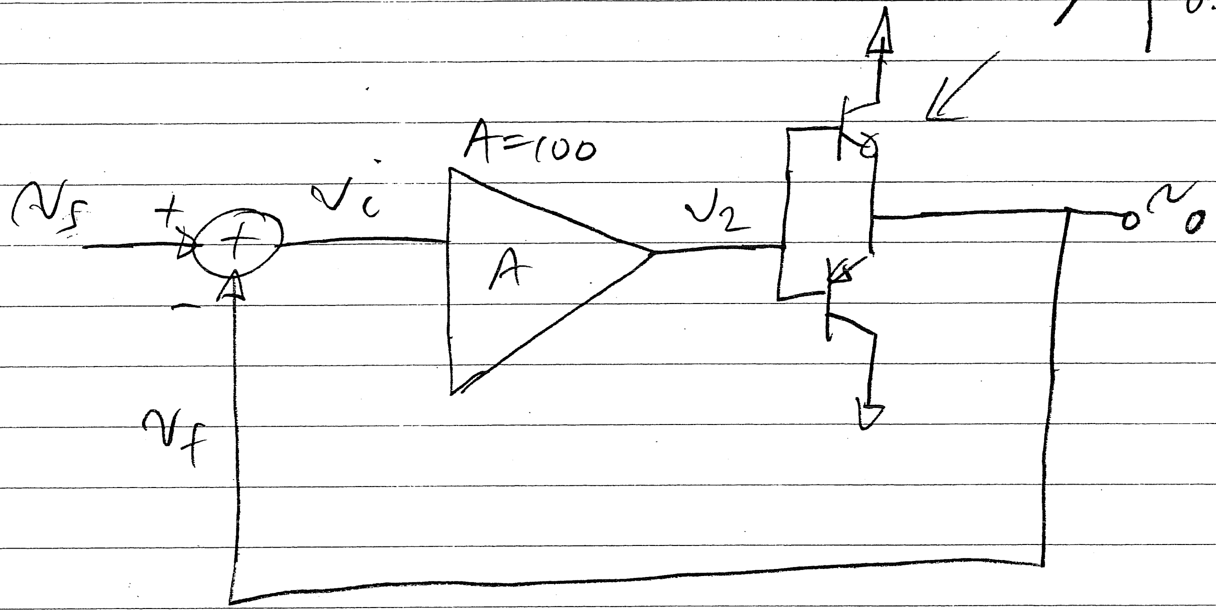
$= 0.96\ V/V$



IF10A

CONSIDER





FOR $v_s = 0 \Rightarrow v_i = 0 \quad v_2 = 0 \quad v_f = 0$ ✓

$v_s = 6mV \Rightarrow v_i = 6mV \quad v_2 = 0.6 \quad v_f = 0$ ✓

$v_s = 0.7mV \Rightarrow v_i = 0.7mV \quad v_2 = 0.7 \quad v_f = 0$ ✓

$v_s = 8mV \Rightarrow v_i = 0.8mV \quad v_2 = 0.8 \Rightarrow v_f = 0.1$

$\Rightarrow v_i \neq 0.8mV$ ✗

WHEN $v_2 > 0.7V \Rightarrow v_o = v_2 - 0.7$

(SINCE SLOPE = 1)

SO WHEN $v_s > 7mV$ WE HAVE

$v_i = v_s - v_f \Rightarrow v_2 = 100\, v_i \Rightarrow v_o = v_2 - 0.7 \Rightarrow v_f = v_o$

OR FOR $v_s > 7\,mV$

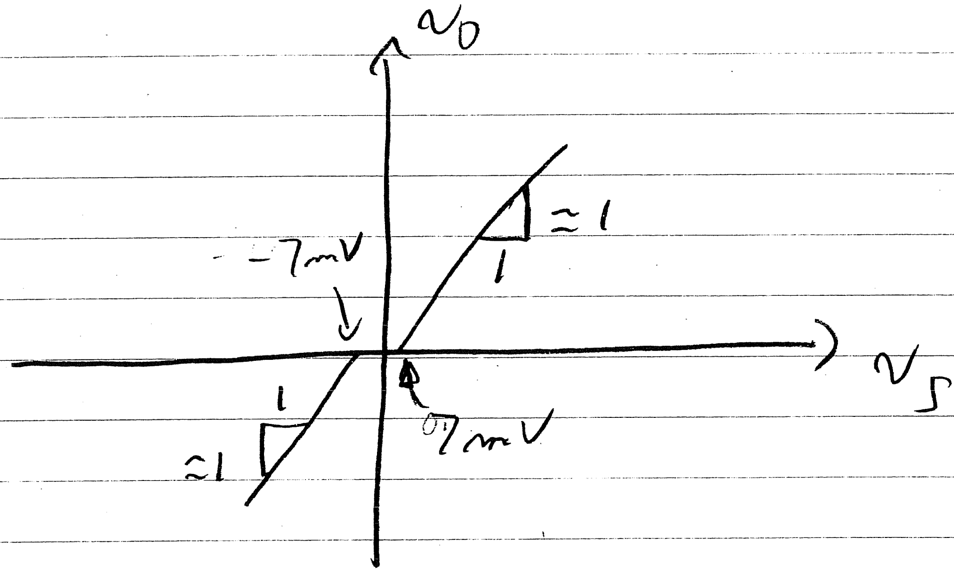
$$(v_s - v_f)100 - 0.7 = v_f$$

EX

$v_s = 8\,mV$

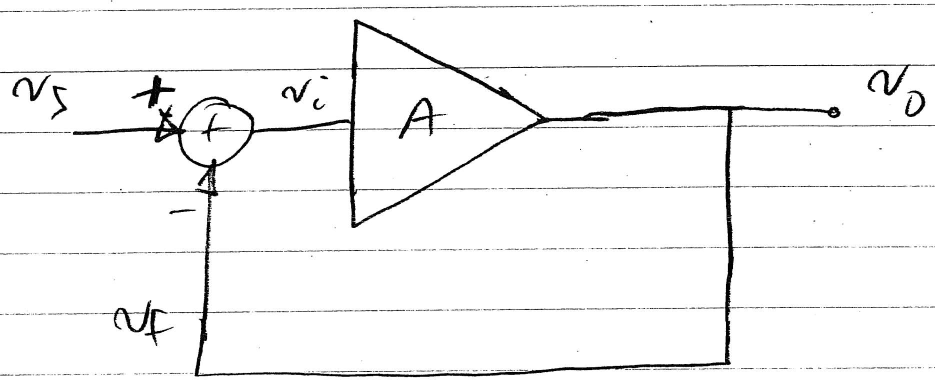
$$(8e{-3} - v_f)100 - 0.7 = v_f$$

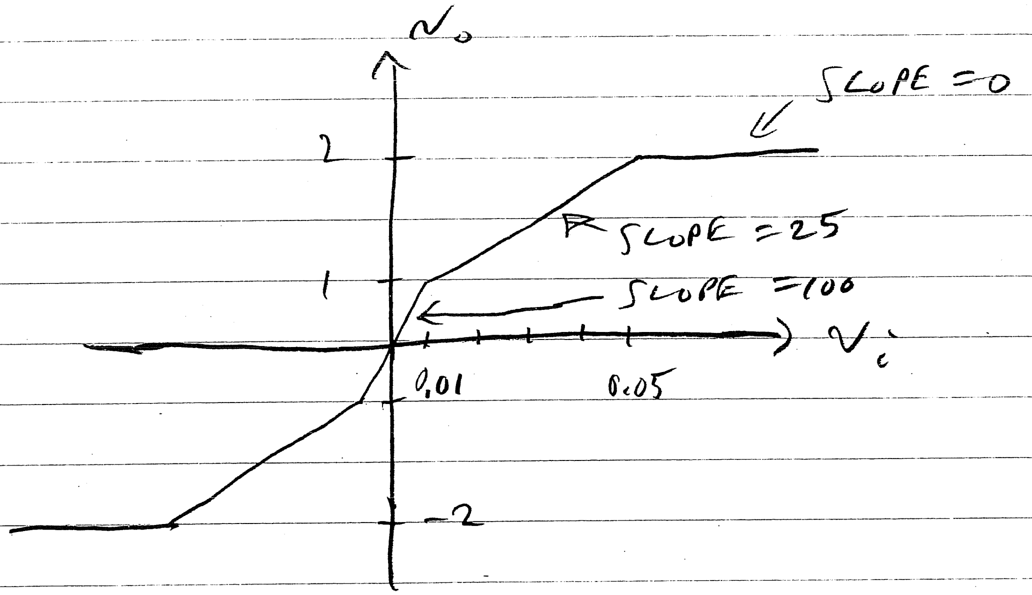
$$101 v_f = 0.1 \Rightarrow v_f = 0.9901\,mV$$



IF10C

CONSIDER





$v_s = 0 \Rightarrow v_i = 0 \Rightarrow v_o = 0 \Rightarrow v_f = 0$ ✓

$v_s = 0.01 \Rightarrow v_i = 0.01 \Rightarrow v_o = 1 \Rightarrow v_f = 1 \Rightarrow v_i \neq 0.01$ ✗

NEED EQUATION

$(v_s - v_f)\,A = v_f$

(IF10D)

FOR $A = 100$ GAIN

$$(v_s - v_f)\,100 = v_f \Rightarrow v_f = \frac{100}{101} v_s$$

$$v_i = v_s - v_f = \frac{101}{101} v_s - \frac{100}{101} v_s = \frac{1}{101} v_s$$

$v_s = 0.01 \Rightarrow v_f = 0.0099$

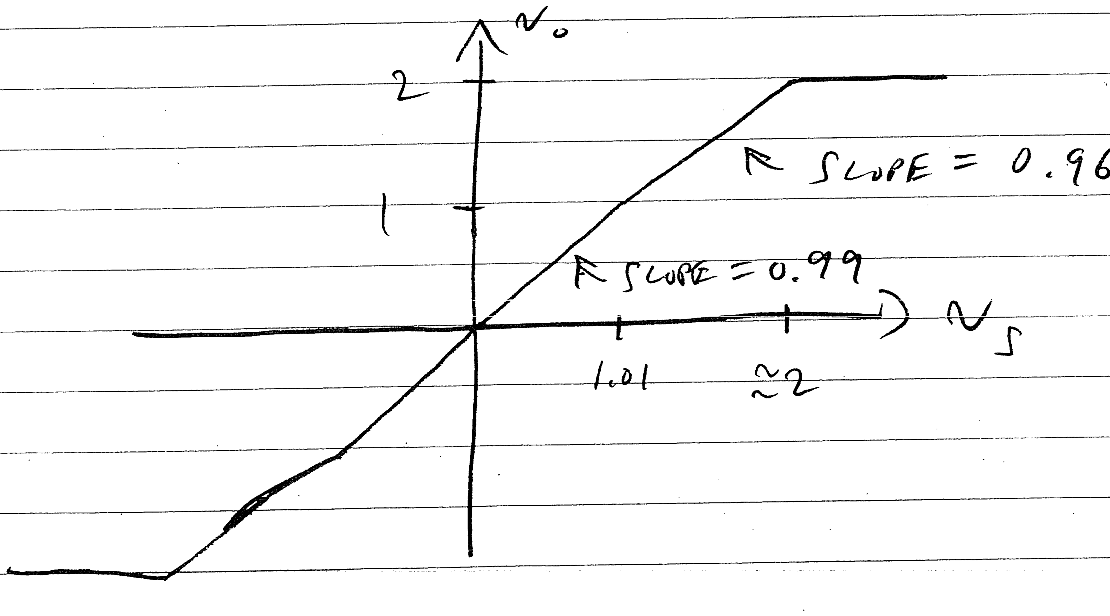
$v_i = 99.01\ \mu V \Rightarrow A = 100$ ✓

(IN GAIN AREA OF $A=100$)

WILL STAY IN GAIN OF $A=100$ UNTIL

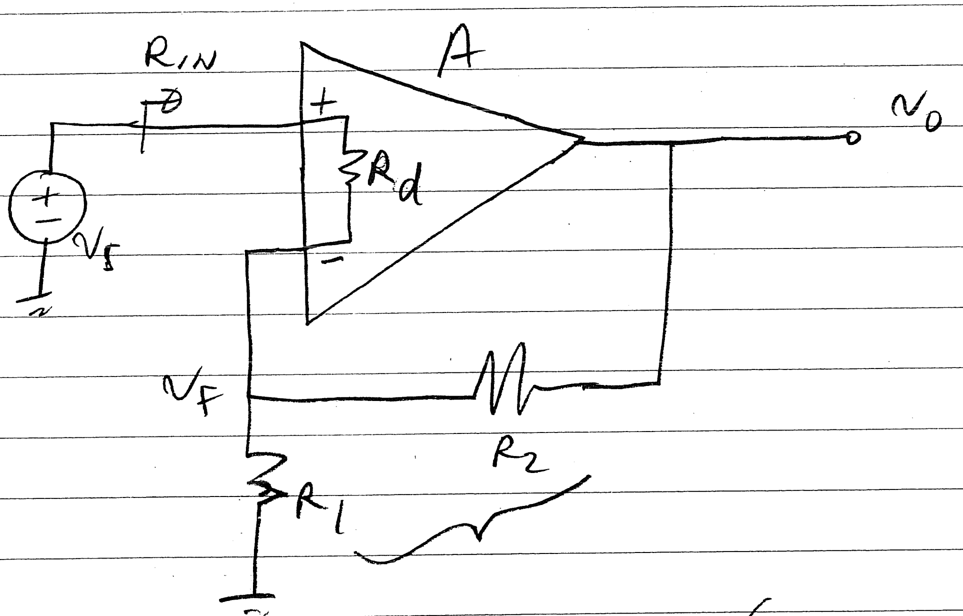
$v_i = 0.01 \Rightarrow v_s = 1.01\ V$

& $v_f = 1\ V$



INPUT/OUTPUT IMPEDANCE ENHANCEMENT

CONSIDER



- WITHOUT FEEDBACK ($R_2 \to \infty$ $R_1 = 0$)

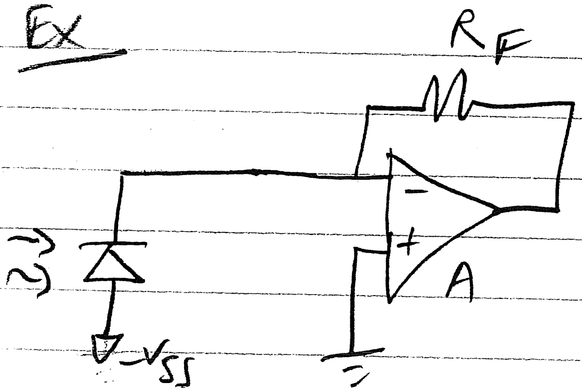
$R_{IN} = R_d$

- WITH FEEDBACK & IF $A\beta \to \infty$
  THEN $v_f = v_s$

  SO $R_{IN} \to \infty$ (SINCE $i_{R_d} \to 0$)

WE WILL SEE THAT GENERALLY FEEDBACK IMPROVES INPUT & OUTPUT IMPEDANCES

EX

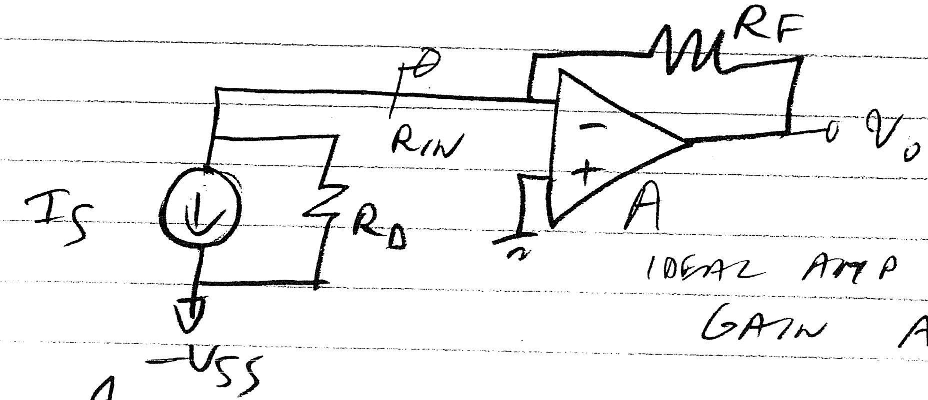


A PHOTO DIODE RECEIVER

DIODE IS REVERSE BIASED. WHEN LIGHT ILLUMINATES PHOTODIODE REVERSE BIAS CURRENT FLOWS

- LIGHT CREATES ELECTRON/HOLE PAIR IN DEPLETION REGION OF REVERSE BIAS JUNCTION. ELECTRONS FLOW TO POSITIVE JUNCTION WHILE HOLES FLOW TO NEGATIVE JUNCTION.

MODEL PHOTO DIODE AS



IDEAL AMP WITH GAIN A

PHOTO DIODE MODEL

- FROM MILLER EFFECT

$$R_{IN} = \frac{R_F}{1+A}$$

AS $A \to \infty$ $R_{IN} \to 0$

SO ALL I_S FLOWS INTO R_F (NONE INTO R_D)

$$V_0 = I_S R_F \quad (\text{AS } A \to \infty)$$

SO R_{IN} IS REDUCED DUE TO FEEDBACK