ECE 342
Electronic Circuits

Lecture 31
Operational Amplifiers - 2

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Frequency Response – Non-Inverting

No feedback	with feedback	description
$A(f)$	$A_{ni}(f)$	Gain
A_{MBOa}	A_{MBni}	Midband gain
f_{2oa}	f_{2ni}	3 dB freq pt
GBW_{oa}	GBW_{ni}	Gain-BW prod

$$A_{MBni} = \frac{A_{MBoa}}{1 + A_{MBoa}F}$$

$$F = \frac{R_a}{R_a + R_F}$$

Frequency Response – Non-Inverting

$$If\ A_{MBoa}F \approx 1,$$

$$A_{MBni} = \frac{1}{F} = \frac{R_a + R_F}{R_a} = 1 + \frac{R_F}{R_a}$$

$$A_{ni}(f) = \frac{A}{1 + AF}$$

$$A(f) = \frac{A_{MBoa}}{1 + jf / f_{2oa}}$$

Frequency Response – Non-Inverting

$$A_{ni}(f) = \frac{A_{MBoa}}{1 + A_{MBoa}F} \cdot \frac{1}{1 + j\dfrac{f}{\left(1 + A_{MBoa}F\right) f_{2oa}}}$$

$$A_{MBni} = \frac{A_{MBoa}}{1 + A_{MBoa}F}$$

$$f_{2ni} = f_{2oa}\left(1 + A_{MBoa}F\right)$$

Frequency Response – Non-Inverting

$$A_{ni}(f) = \frac{A_{MBni}}{1 + jf / f_{2ni}}$$

$$GBW_{ni} = A_{MBni} f_{2ni} = \frac{A_{MBoa}}{1 + A_{MBoa} F} \cdot f_{2oa} \left(1 + A_{MBoa} F\right)$$

$$GBW_{ni} = A_{MBni} f_{2ni} = A_{MBoa} f_{2oa} = GBW_{oa}$$

Gain-Bandwidth product is constant

Frequency Response – Non-Inverting

Midband voltage gain is reduced from A_{MBoa} to A_{MBni}

The upper 3-dB frequency will be greater than that of the op amp by the same factor of gain reduction.

If the low-frequency gain of the op amp is A_{MBoa}= 200,000 and with resistors A_{MBni} = 40, the gain is reduced by a factor of 5,000. If the basic 3-db frequency is 5 Hz, the noninverting 3dB frequency will be 25 kHz.

Frequency Response – Inverting OP Amp

$$A_i = \frac{-AR_F}{R_1(1+A)+R_F}$$

Using $A = \dfrac{A_{MBoa}}{1+jf/f_{2oa}}$

$$A_i = \frac{-A_{MBoa}R_F}{R_1(1+A_{MBoa})+R_F+j\left(R_1+R_F\right)f/f_{2oa}}$$

Frequency Response – Inverting OP Amp

Using $R_1\,(A_{MBoa}+1) \approx R_1 A_{MBoa}$

and neglecting R_F

$$A_i = \frac{R_F}{R_1} \cdot \frac{1}{1 + j\dfrac{f}{f_{2oa}\left(1 + A_{MBoa} R_1 / [R_1 + R_F]\right)}}$$

Frequency Response – Inverting OP Amp

$$A_{MBi} = \frac{-R_F}{R_1}$$

$$f_{2i} = f_{2oa}\left(1 + A_{MBoa} R_1 / [R_1 + R_F]\right)$$

$$A_{MBi} f_{2i} = f_{2oa}\left(1 + A_{MBoa}\frac{R_1}{R_1 + R_F}\right)\left(\frac{-R_F}{R_1}\right)$$

Frequency Response – Inverting OP Amp

$$A_{MBi} f_{2i} = -f_{2oa}\left(1 + A_{MBoa}\frac{R_F}{R_1 + R_F}\right)$$

$$A_{MBi} f_{2i} \approx -f_{2oa} A_{MBoa}$$

if $R_F >> R_1$

$$A_i(f) = \frac{A_{MBi}}{1 + jf / f_{2i}}$$

Frequency Response – Inverting OP Amp

if $R_F >> R_1$ gain-bandwidth is constant

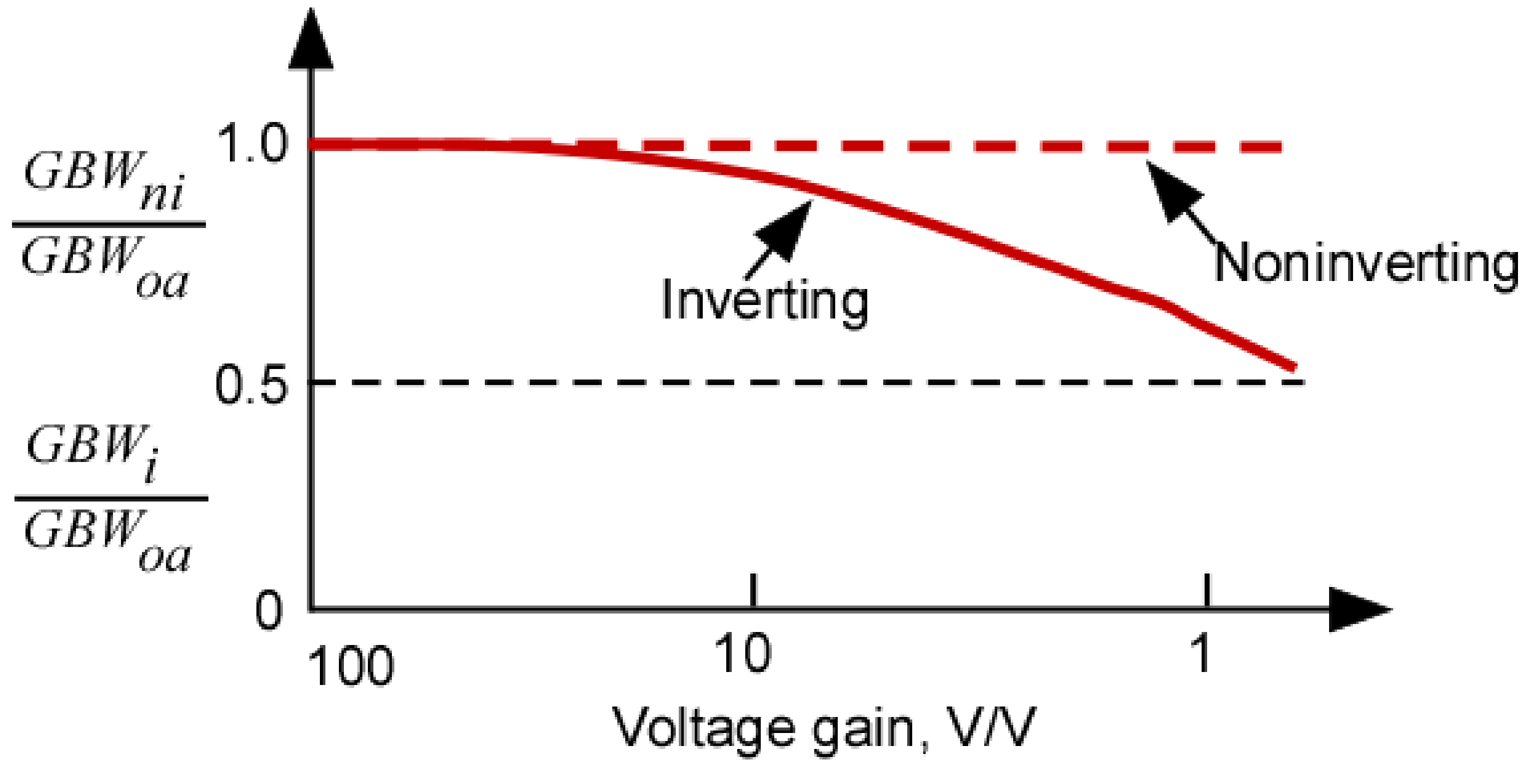
if $R_F \sim R_1$,

$$GBW_i = \left| A_{MBi} \right| f_{2i} \approx A_{MBoa} f_{2oa} \frac{R_F}{R_F + R_1}$$

$$GBW_i \approx GBW_{oa} \frac{R_F}{R_F + R_1}$$

Frequency Response – Inverting OP Amp

$$f_{2i} = GBW_{oa}\frac{R_F}{R_F + R_1}\cdot\frac{1}{|A_{MBi}|} = \frac{GBW_{oa}R_1}{R_F + R_1}$$



Example

Design an amplifier to couple a microphone to a resistive load. The microphone generates a peak output of 50 mV for a typical voice input level and has a 10-kΩ output impedance. The output voltage across the 2-kΩ load is to have a peak value of 10 V. the bandwidth of the voltage gain should be at least 40 kHz. If the GBW of the op amp used is 3×10^6 Hz, calculate the bandwidth of the final design

The midband voltage gain is:

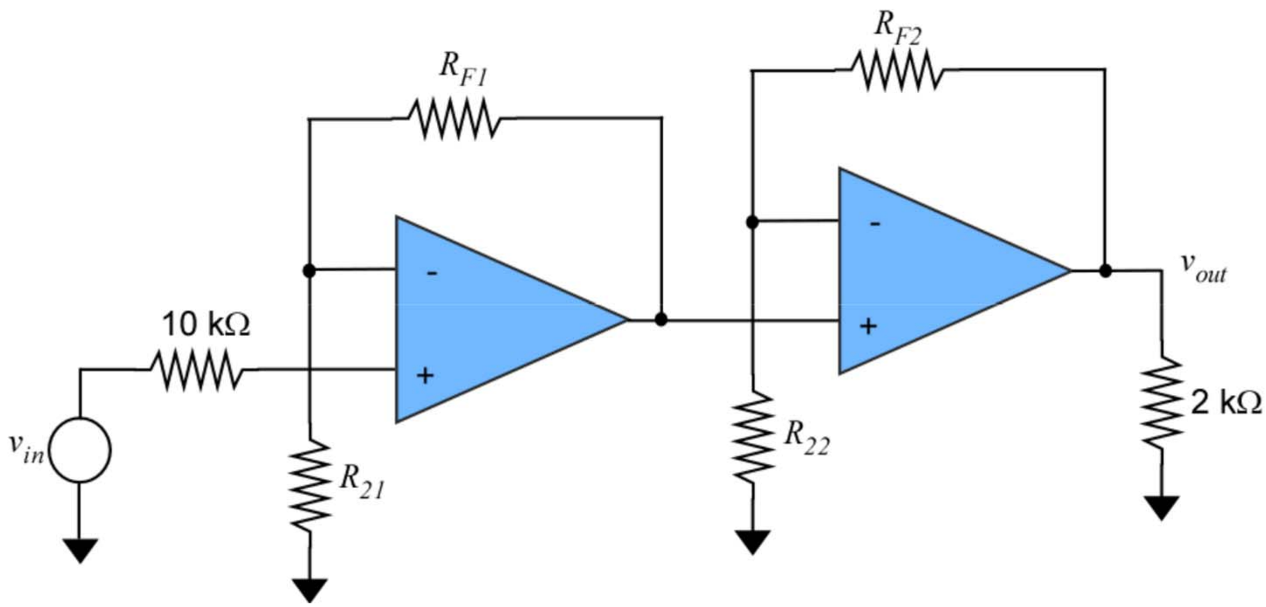
$$A_{MBo} = \frac{10}{0.05} = 200$$

For a single noninverting stage with this gain, the upper corner frequency is:

$$f_{2ni} = \frac{GBW_{ni}}{A_{MBni}} = \frac{GBW_{oa}}{A_{MBni}} = \frac{3\times10^6}{200} = 15\ kHz$$

Example (cont')

This value of BW will not work → need 2 stages



Pick first stage gain 10; second stage gain 20. We must then have:

$$1+\frac{R_{F2}}{R_{22}}=20$$ and $$1+\frac{R_{F1}}{R_{21}}=10$$

Example (cont')

Choose R_{21} and R_{22} arbitrarily and use above equations to extract R_{F1} and R_{F2}; we get:

R_{F1}= 18 kΩ, R_{F2} = 38 kΩ

Next, find 3-dB bandwidth of each stage by dividing respective gains into GBW_{oa} or GBW_{ni}

$$f_{2ni1} = \frac{3\times 10^6}{10} = 300\ kHz$$

$$f_{2ni2} = \frac{3\times 10^6}{20} = 150\ kHz$$

Example (cont')

The overall gain is:

$$A_o(\omega) = \frac{10}{1 + jf/3\times10^5}\frac{20}{1 + jf/1.5\times10^5}$$

At 3dB point, magnitude squared of denominator must be 2

$$2 = \left(1 + \frac{f_{2o}^2}{9\times10^{10}}\right)\left(1 + \frac{f_{2o}^2}{2.25\times10^{10}}\right)$$

From which

$$f_{2o} = 126\ kHz$$